

PB 204 522

Final Report

FOAM SUPPRESSION OF RESPIRABLE COAL DUST

Authors

I.O. Salyer
S.M. Sun
J.L. Schwendeman
A.L. Wurstner

For

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

U.S. Department of the Interior

Bureau of Mines

Washington, D.C. 20240

Contract H0100179

Bureau of Mines Open File Report 10-71

MONSANTO RESEARCH CORPORATION

A SUBSIDIARY OF MONSANTO COMPANY

D A Y T O N
L A B O R A T O R Y

DAYTON, OHIO 45407

BIBLIOGRAPHIC DATA SHEET	1. Report No. BuMines OFR 10-71	2.	3. Recipient's Accession No.												
	4. Title and Subtitle Foam Suppression of Respirable Coal Dust Final Report		5. Report Date Dec. 70												
7. Author(s) I.O. Salyer, S.M. Sun, J.L. Schwendeman, and A.L. Wurstner		6. Performing Organization Code													
9. Performing Organization Name and Address Monsanto Research Corporation Dayton Laboratory Dayton, Ohio 45407		8. Performing Organization Rept. No. MRC-DA-274													
12. Sponsoring Agency Name and Address Bureau of Mines Office of Assistant Director--Mining U.S. Department of the Interior Washington, D.C. 20240		10. Project/Task/Work Unit No.													
		11. Contract/Grant No. Contract HO100179													
15. Supplementary Notes		13. Type of Report & Period Covered Research: Nov. 1969 to Oct. 1970													
		14. Sponsoring Agency Code													
16. Abstracts This report describes research in the control and suppression of respirable coal mine dust in order to prevent coal miners from developing pneumoconiosis. A formulation was developed for making a water-based, high-expansion, and limited stability foam. A horizontal boring machine was used as a laboratory coal mining model for generating coal dust. A modified laboratory foam generator was built. Foam was applied directly to the point at which dust was being formed by the cutter of the boring machine working against a block of coal. Coal dust was sampled with an impinger and analyzed for the particle count and particle size distribution. Coal dust suppression test results on freshly generated dust demonstrated that in laboratory-scale experiments more than 90 percent of the respirable coal dust could be suppressed by foam. Tests were run when the initial coal dust concentrations were 10 and 70 million particles per cubic foot.															
17. Key Words and Document Analysis. 17a. Descriptors															
<table border="0"> <tr> <td>Coal dust</td> <td>Pneumoconiosis</td> <td>Coal mining</td> </tr> <tr> <td>Coal mines</td> <td>Respiratory diseases</td> <td>Mine ventilation</td> </tr> <tr> <td>Mine ventilation</td> <td>Coal mines</td> <td>Dust control</td> </tr> <tr> <td>Pneumoconiosis</td> <td>Dust control</td> <td>Foam application</td> </tr> </table>				Coal dust	Pneumoconiosis	Coal mining	Coal mines	Respiratory diseases	Mine ventilation	Mine ventilation	Coal mines	Dust control	Pneumoconiosis	Dust control	Foam application
Coal dust	Pneumoconiosis	Coal mining													
Coal mines	Respiratory diseases	Mine ventilation													
Mine ventilation	Coal mines	Dust control													
Pneumoconiosis	Dust control	Foam application													
17b. Identifiers/Open-Ended Terms															
17c. COSATI Field/Group 13A, 13L, 8I															
18. Distribution Statement Release unlimited. Releasable to the public.		19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 63												
		20. Security Class (This Page) UNCLASSIFIED	22. Price												

FOAM SUPPRESSION OF RESPIRABLE COAL DUST

Final Report

Authors

I. O. Salyer
S. M. Sun
J. L. Schwendeman
A. L. Wurstner

U. S. Department of the Interior
Bureau of Mines
Washington, D. C. 20240

Contract HO100179

Bureau of Mines Open File Report 10-71

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
Dayton, Ohio 45407

BuMines OFR 10-71

December 1970

MRC Job No. 6765

FOREWORD

This contract was awarded by the Bureau of Mines to Monsanto Research Corporation, Dayton Laboratory, Dayton, Ohio 45407. The contract number was HO100179, and the project officer was Mr. Norman E. Hanna. The contract work was conducted by I. O. Salyer (section manager), J. L. Schwendeman (research group leader), A. L. Wurstner (research microscopist), S. M. Sun (senior research chemical engineer) and N. E. Jones (technician). During this study, advice was obtained from Mr. J. C. Harris and Professor J. Outwater (Monsanto Research Corporation consultants). This work was started in November 1969 and completed in October 1970. The final report was submitted in December 1971.

As a result of this study, the application of the EMA-54 foam for the suppression of respirable coal dust is considered as an invention. A patent disclosure has been filed. EMA-54 is the sodium salt of ethylene maleic anhydride copolymer made by Monsanto Company.

ABSTRACT

This research was conducted with the objective of suppressing the respirable dust in coal mines by foam application. A formulation was developed for making a water-based, high-expansion, and limited stability foam. A horizontal boring machine was used as a laboratory coal mining model for generating coal dust. A modified laboratory foam generator was built. Foam was applied directly to the point at which dust was being formed by the cutter of the boring machine working against a block of coal. Coal dust was sampled with an impinger and analyzed for the particle count and particle size distribution. Coal dust suppression test results on freshly generated dust have demonstrated very clearly that in laboratory scale experiments over 90% of the respirable coal dust can be suppressed by foam. These tests were run when initial coal dust concentrations were 10 and 70 million particles per cubic foot (mppcf).

LIST OF TABLES

<u>Table No.</u>		<u>Page No.</u>
1	CONTACT ANGLE DATA	7
2	EXPANSION FACTORS OF ELVANOL FOAMS	14
3	EXPANSION FACTORS OF GELVATOL FOAMS	14
4	EXPANSION FACTORS OF WATER-BASED FOAMS WITH VARIOUS FOAMING AGENTS OR SURFACTANTS	16
5	EXPANSION FACTORS OF WATER/SURFACTANT FOAMS WITH THE SURFACTANT AS FOAMER	17
6	CONTACT ANGLES BETWEEN COAL SURFACE AND VARIOUS FOAM SOLUTIONS	18
7	EXPANSION FACTORS OF FOAMS OF VARIOUS COMPOSITIONS	19
8	EXPANSION FACTORS OF FOAMS FROM EMA-54 SOLUTIONS OF VARIOUS CONCENTRATIONS	19
9	PROPERTIES OF 0.5% EMA-54 SOLUTIONS PREPARED WITH DIFFERENT KINDS OF WATER	20
10	EXPANSION FACTORS OF FOAMS OF 0.5% EMA-54 SOLUTIONS IN DIFFERENT KINDS OF WATER	20
11	PROPERTIES OF 0.5% EMA-54 SOLUTIONS IN WATER OF DIFFERENT PH	21
12	EXPANSION FACTORS OF FOAMS OF 0.5% EMA-54 SOLUTIONS IN WATER OF DIFFERENT PH	21
13	EXPANSION FACTOR RANGES OF FOAMS OF EMA-54 SOLUTIONS OF VARIOUS CONCENTRATIONS	22
14	COAL DUST GENERATION EXPERIMENT DATA	31
15	CALCULATED AMOUNTS OF COAL DUST PRODUCED UNDER DIFFERENT CUTTING CONDITIONS	31
16	RESULTS OF COAL DUST SUPPRESSION EXPERIMENT AT LOW COAL DUST CONCENTRATION	32

LIST OF TABLES

<u>Table No.</u>		<u>Page No.</u>
17	INCREASED PRODUCTION OF COAL DUST	38
18	PARTICLE COUNT DATA OF COAL DUST SAMPLES TAKEN BEFORE AND DURING FOAM APPLICATION	39
19	PERCENT COAL DUST SUPPRESSED WITH DIFFERENT AMOUNTS OF FOAM	40
20	ANALYSIS OF COAL DUST PARTICLE SIZE AND DISTRIBUTION	46
21	PARTICLE SIZE DISTRIBUTION DATA OF COAL DUST SAMPLES TAKEN BEFORE AND DURING FOAM APPLICATION AT DIFFERENT DUST CONCENTRATION LEVELS	47

LIST OF FIGURES

<u>Figure No.</u>		<u>Page No.</u>
1	Contact Angle	8
2	Contact Angle Measuring Device	9
3	Schematic Drawing of Foam Generator	12
4	Schematic Layout of the Lab Coal Mining Model	26
5	Horizontal Boring Machine	27
6	Coal Cutting	28
7	Coal Dust Sampling System	29
8	Top View Sketch of the Coal Cutting Arrangement	30
9	Depth of Coal Cut vs Particle Count	33
10	Schematic Drawing of the Vacuum Pump Coal Dust Sampling Device	34
11	Photomicrographs	36
12	Photomicrographs	37
13	Percent Coal Dust Suppressed with Various Amounts of Foam	41
14	Simplified Block Diagram of Quantimet	43

TABLE OF CONTENTS

	<u>Page No.</u>
1. INTRODUCTION	1
2. SUMMARY	3
3. TECHNICAL DISCUSSION	5
3.1 DEVELOPMENT OF A FOAM FORMULATION SUITABLE FOR WETTING DOWN THE COAL DUST	5
3.1.1 Evaluation of Surfactants	5
3.1.2 Foam Generation	10
3.1.3 Evaluation of Polymers	11
3.1.4 Evaluation of Foaming Agents	16
3.1.5 Evaluation of Foam Solutions	17
3.1.6 Recommended Foam Formulation	21
3.2 DEVELOPMENT OF A LABORATORY COAL MINING MODEL	23
3.2.1 Selection of Simulation Method	23
3.2.2 General Layout	25
3.2.3 Coal Dust Generation	25
3.2.4 Coal Dust Sampling	32
3.3 COAL DUST SUPPRESSION EXPERIMENTS	35
3.3.1 Coal Dust Suppression Test at Low Dust Concentration	35
3.3.2 Coal Dust Suppression Test at High Coal Dust Concentration	38
3.3.3 EMA-54/Tergitol Solution as a Binder for Coal Dust	40
3.4 ANALYSIS OF COAL DUST SAMPLES	42
3.4.1 Particle Count Determination	42
3.4.2 Particle Size Distribution	45
4. CONCLUSIONS	48
5. RECOMMENDATIONS	49
6. BIBLIOGRAPHY	50

TABLE OF CONTENTS

	<u>Page No.</u>
7. APPENDIX	51
7.1 MATERIALS USED AND EVALUATED	51
7.2 EQUIPMENT USED	53
7.3 PROGRAM OF STUDY	54

1. INTRODUCTION

In recent years it has become clear that many coal miners develop the so-called "black lung" disease, which is more appropriately designated as "pneumoconiosis". The control and suppression of respirable coal mine dust is necessary for the prevention of this disabling disease.

According to the manual issued by the Bureau of Mines entitled "Sampling and Evaluation of Respirable Coal-Mine Dust" (for Mineral Industry Health Program Training Course 100), there are now two criteria accepted for defining respirable dust. The first, resulting from work performed within the U.S. Atomic Energy Commission, is defined by a sampling efficiency curve that passes through the following points: (1) effectively 100% efficiency at 2 microns and smaller, (2) 50 percent efficiency at 3.5 microns, and (3) zero efficiency for particles 10 microns and larger. The other criteria for the respirable fraction of dust, recommended and adopted by the Johannesburg Pneumoconiosis Conference, is defined by a sampling efficiency curve that passes through the following points: (1) effectively 100% efficiency at 1 micron and smaller, (2) 50% efficiency at 5 microns, and (3) zero efficiency for particles of 7 microns and larger.

A number of methods have been adopted to suppress the respirable coal mine dust. The most popular practices are (1) ventilation, (2) water spray, (3) water infusion, (4) water/wetting agent spray, (5) modified machine design, (6) foam application. Currently, the general practice in coal mines is the combination of ventilation and water spray. Foam application was initially studied in British coal mines.

Preliminary results from the study on foam application in U. S. coal mines did indicate the effectiveness of foam (Ref 1). However, the foam expansion factor, application method, and cost problems remained to be studied.

It appears probable that in order to suppress respirable coal dust, the most important point is to wet down the dust particles before they become airborne. Once they become airborne, it will be very difficult to trap these "gas-like" particles.

When water spray is used, regardless of the fineness of the droplets, there always exist "empty spaces" between the water droplets. The respirable dust particles will easily "escape" through these "empty paths". On the other hand, the foam is composed of layers of films that will catch the dust particles much more easily. Moreover, as compared to water spray, high expansion foam will cover much more space with the same amount of water.

The Bureau of Mines awarded a contract to Monsanto Research Corporation to study the suppression of respirable coal dust by foam. The program was set up with the following objectives:

- (1) To develop an adequate formulation for making a foam with sufficient stability and strength to trap and wet the coal dust. The foam should collapse reasonably soon after generation. It should be non-toxic and non-irritating to the coal miner, and should not damage the coal mining equipment.
- (2) To demonstrate the feasibility of foam suppression of respirable coal dust in the laboratory using a laboratory-scale mining model. Develop a foam generator to match the scale of coal dust production and sample the dust using conventional coal mine sampling techniques. The samples should be analyzed for particle count and particle size distribution.

2. SUMMARY

- (1) Eight anionic, 8 cationic, 18 nonionic, and 6 other surfactants were evaluated for their ability to wet coal by measuring the contact angle between the coal surface and the aqueous solution of each of these surfactants. Based upon their contact angles (10 degrees or less) with the coal surface, 15 surfactants were selected for further evaluation.
- (2) Two kinds of polymers, polyvinyl alcohol and water-soluble ethylene/maleic anhydride copolymers, were evaluated as foam solution ingredients using gelatin as a reference. Based upon the foaming performance (foam expansion factor and stability), EMA-54 (the sodium salt of ethylene/maleic anhydride copolymer) was shown to be the most promising candidate.
- (3) Among the 15 surfactants initially selected, Tergitol TMN (a nonionic surfactant manufactured by Union Carbide) was found to be the most suitable ingredient to serve as both a wetting agent for coal dust and as a foaming agent. Its aqueous solution produced good foams and wet coal very efficiently. When Tergitol TMN and EMA-54 were combined, the good foaming and coal wetting properties were retained.
- (4) The foam formulation was developed as follows:

0.1-1.0% EMA-54 aqueous solution	100 parts
Tergitol TMN	0.5 parts

The foam expansion factor (50-400:1) and stability can be varied by adjusting the EMA-54 concentrations and the foam generating conditions.

The EMA-54 serves not only as a foam reinforcement but also as a binder of the wetted coal dust. Both EMA-54 and Tergitol TMN have been classified as non-toxic. Pure, concentrated Tergitol TMN may cause skin and eye irritation. However, when it is diluted to about 0.5%, the hazard is greatly reduced.

- (5) A laboratory-scale coal mining model was set up for the demonstration of the feasibility of foam suppression of coal dust. A horizontal boring mill using a fly cutter was used to generate coal dust under controlled and reproducible conditions. A "scaled-down" laboratory foam generator was developed and used for the foam application during tests. An exhaust duct was installed to provide adequate draft and coal dust sampling connections. Impinger units were used for collecting coal dust samples.

- (6) At first, coal dust suppression tests were conducted at low dust concentration (around 10 mppcf*), with successful results. Over 90% of the coal dust was removed by foam application. Then, the coal mining model was adjusted to produce increased amounts of dust up to 70 mppcf. Coal dust suppression tests were run at this high concentration level. Again, over 90% of the coal dust was suppressed. Tests were also carried out to suppress the same concentration of coal dust with different amounts of foam. It was indicated that coal dust was substantially (over 80%) removed by a reduced amount of foam (35 ml foam solution per minute instead of normally used 300 ml).
- (7) Coal dust samples were analyzed for particle count with a quantitative television microscope (Q.T.M.). Particle size distribution was checked with a microscope. It was found that coal dust particles were suppressed in proportion to the particle size distribution.

*mppcf=million particles per cubic foot

3. TECHNICAL DISCUSSION

3.1 DEVELOPMENT OF A FOAM FORMULATION SUITABLE FOR WETTING DOWN THE COAL DUST

3.1.1 Evaluation of Surfactants

A surfactant (surface-active agent) is a material that affects (usually reduces) the surface tension when dissolved in a solvent (usually water) or that tends to reduce the interfacial tension between two materials. Thus, a surfactant may cause water to penetrate more easily into, or to spread over the surface of, another material (like coal). In this case, the surfactant serves as a wetting agent.

Generally, surfactants are classified as anionic, cationic, nonionic, and ampholytic. Anionics and nonionics are used as wetting agents. Anionics are generally alkyl aryl sulfonates, alkyl sulfates, sulfated and sulfonated amides and amines or esters and ethers. Nonionic surfactants refer chiefly to polyoxyethylene and polyoxypropylene derivatives. Nonionics function independently of water hardness and pH. The stability of nonionic surfactants toward salt solutions, hard water, earth alkali or heavy metal salt solutions is usually far greater than that of cationic or anionic agents of a similar degree of water solubility. Their compatibility with solvents and chemicals is more extensive than that of the ionic types. Coal dust particles are easily wettable by oil but not by water. Generally, an oil-wettable substance is likely to be negatively charged. Therefore, anionic surfactants may not work well in suppressing coal dust even though a few of them did show very good coal dust wettability (Table 1). A nonionic surfactant would be the more probable candidate as a coal dust wetting agent.

Forty surfactants were evaluated in this study. Their compatibility with water and wetting action on coal were studied.

3.1.1.1 Compatibility with Water

A water-base foam was to be formulated. It was thus desirable that the surfactant be soluble in water. Several water-insoluble surfactants were eliminated on this basis from the evaluation at the very beginning. Three surfactants among the forty (40) candidates were soluble in water only at higher temperatures. They are:

- Igepon AC-78 which was soluble in water at 72°C but not readily at 25°C;

- Emulphor ON-870, which was soluble in water at 72°C; and
- Lubrol WX, which dissolved readily in water at 50°C; but slowly in cold water.

Most of the other surfactants dissolved in water readily even though several water/surfactant mixtures needed shaking or stirring. Since the surfactant was to be used in very low proportions in the water/surfactant mixture, its solubility in water was not necessarily high. Dayton city water was used mainly for this study. Its pH was determined as 8.35.

3.1.1.2 Contact Angle Measurement

The wettability of coal with the surfactants was determined by the measurement of the contact angle between a drop of aqueous surfactant solution on the coal surface (See Figure 1). A fresh area of coal surface was used for each test. The contact angle (θ) defines the wettability. When the surfactant solution wets the coal completely and spread freely over the surface, the contact angle equals to zero ($\theta=0$). Thus, the tendency for the surfactant solution to spread over the coal surface increases as θ decreases. The contact angle is a useful inverse measure of spreadability or wettability.

To measure the contact angle, an instrument designed and fabricated by our laboratory was used. It consisted of a goniometer eyepiece attached to a telescope (Figure 2). Coal slabs, each with the dimensions of 1-1/4 in. x 3/4 in. x 7/16 in. were cut from a large lump of bituminous coal from West Virginia and polished. The slab was placed horizontally between the telescope and a diffused light source. A drop of surfactant solution was put on the coal slab surface by means of a syringe.

The contact angle was measured three minutes after the drop was placed on the coal. Most of the surfactants were mixed with water in three surfactant/water proportions: 1/900, 1/1200, and 1/1500. Contact angle between each of these three mixtures and coal surface was determined with the results listed in Table 1.

Table 1
CONTACT ANGLE DATA

Material Name	Contact Angle (degrees)		
	1*	2*	3*
Dayton City Water (100%)		67*	
<u>Anionic Surfactant</u>			
Acto 450	41	44	46
DDBSA 99-B	0**	-	-
DDBSA 99-UB	0***	-	-
Dowzit AHB	54	55	55
Igepon AC-78	21	21	30
Monawet MO-70	0***	-	-
Santomerse ME-B Slurry	2**	-	-
Sipex JKB	35	37	44
<u>Cationic Surfactant</u>			
Aliquat 21	26	26	32
Aliquat 33	10	17	17
Atlas G-2090	21	30	31
Emcol E-12	3	12	16
Katapol PN-430	23	27	27
Monazoline O	18	20	21
Monazoline T	17	19	19
Romine O	17	17	17
<u>Nonionic Surfactant</u>			
Barlox E105	21***	-	-
Brij 35	14	27	29
Emulphor ON-870	31	31	33
Hallecomid M8-10	15	23	29
Igepol CO-630	25	25	25
Igepol CO-730	25	26	27
Kyroc EOB	10	15	15
Lubrol WX	27	35	29
Peregál O	30	33	44
Poly-Tergent J-300	2	3	3
Renex 30	10	11	11
Sterox AJ	10	17	17
Tergitol 15-S-9	30	30	30
Tergitol TMN	1	6	12
Tetronic 702	30	-	-
Tetronic 1102	24	-	-
Tetronic 1302	10	-	-
Triton X-100	8	10	14
<u>Nonionic Surfactant with Cationic Nature</u>			
Amidox C-5	6	18	24
Amidox L-5	12	13	16
<u>Ampholytic Surfactant</u>			
Atlas G-3780A	30	32	32
<u>Experimental Surfactant</u>			
Mona R35 15-11	10	-	-
Mona R35 15-40	4	-	-
Mona R35 15-54	14	-	-

*Contract angle readings 1,2, and 3 were corresponding to aqueous surfactant solution concentrations of 1/900, 1/1200 and 1/1500, respectively, except that of water.

**0.5 g of surfactant in 30 ml of water

***5 drops (equivalent to 1/6 ml) of surfactant in 30 ml of water

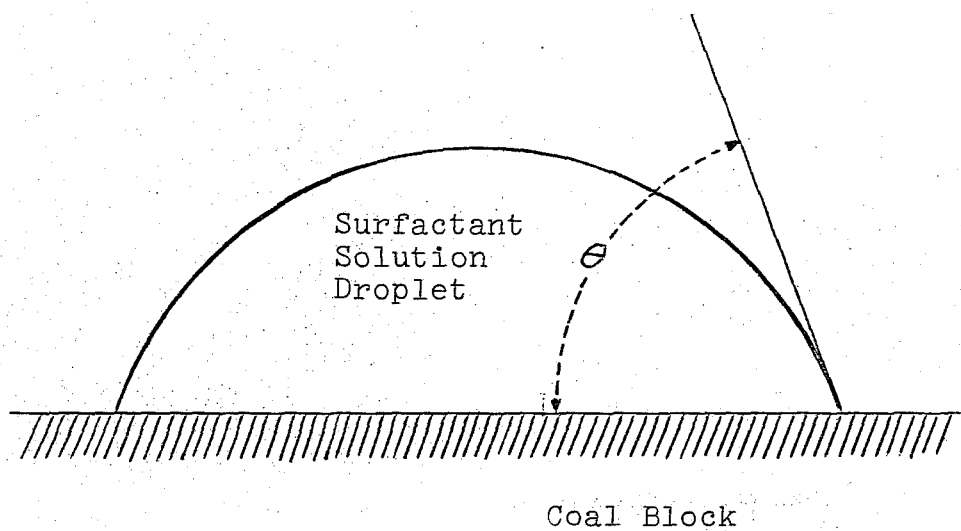


Figure 1. Contact Angle (θ)

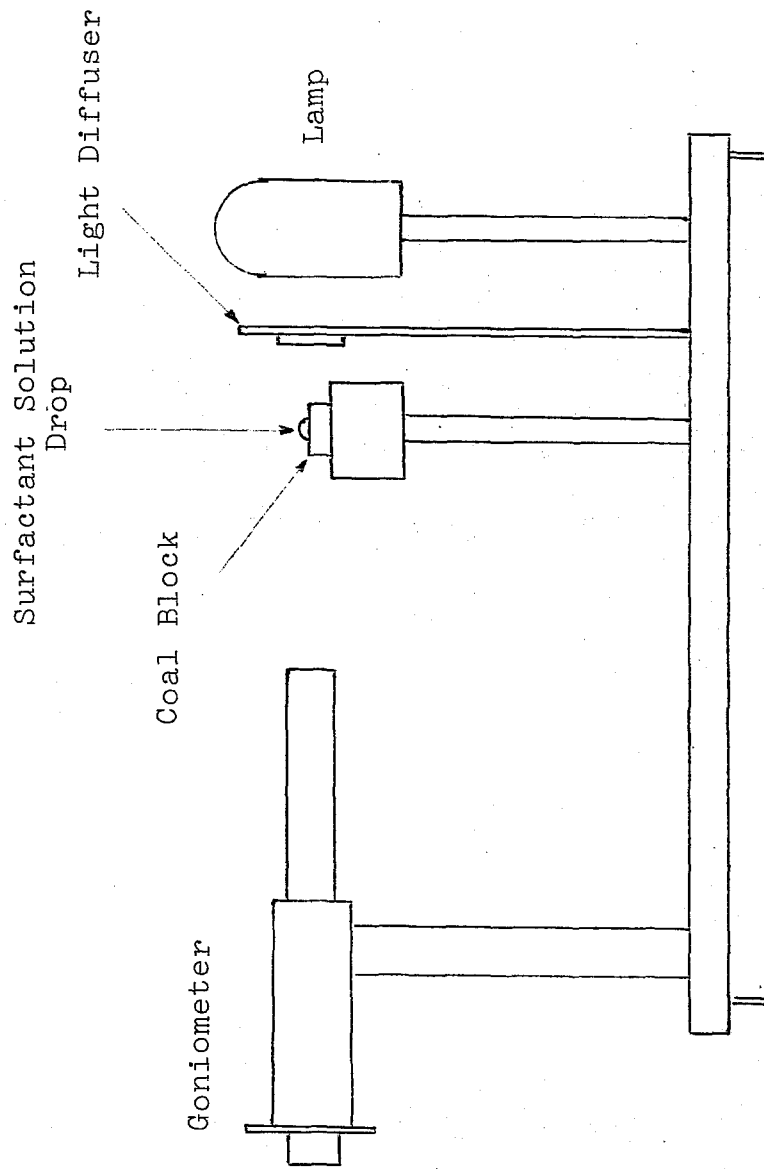


Figure 2. Contact Angle Measuring Device

From Table 1, fifteen (15) surfactants were selected for further evaluation. The contact angle between the coal surface and each of these surfactants (in aqueous solution) as determined, was equal to or less than 10 degrees. These fifteen surfactants were:

DDBSA 99-B	Kyro EOB	Tetronic 1302
DDBSA 99-UB	Poly-Tergent J-300	Triton X-100
Monawet MO-70	Renex 30	Amidox C-5
Santomerse ME-B Slurry	Sterox AJ	Mona R-35 15-11
Emcol E-12	Tergitol TMN	Mona R-35 15-45

3.1.2 Foam Generation

A foam consists of a mass of gas bubbles dispersed in a solid or liquid matrix. Low-density foams are dispersions of relatively large volumes of gas in relatively small volumes of solid or liquid. For this study, only low-density, water-based and limited-stability foams were to be developed.

3.1.2.1 General Foam Formulation

As a starting point, a general foam formulation was set up for this program. Generally, a foam for dust suppression should be made of the following four ingredients:

Water- the basic material
Surfactant- the coal dust wetting agent
Foaming agent- the foamer
Polymer- the reinforcement material

The first three components are essential to foaming and wetting the dust. The polymer addition which is characteristic of high expansion foams developed by Monsanto Research Corporation, is needed to provide "toughness" to the foam.

Water constitutes the main body of the foam. During the later part of this study, it was observed that the polymer in the foam composition also served as a binder for the wetted coal dust. One of the surfactants with a small contact angle between its aqueous solution and coal surface was used in the foam formulation. Finally, based upon our past experience, Hi-Ex 15 AE + 35, was a very good foaming agent for water-based foam.

3.1.2.2 Foam Generator

The water-based, low-density foam for dust suppression was generated with a system developed in our laboratory. It consisted of three components: (1) the foam solution reservoir, (2) the spray nozzle and screen, and (3) the air blower. In use, foam solution is pushed by compressed air or N₂ (in actual mine use, a pump would be used) and sprayed through the nozzle onto the screen. It is blown into foam by the air from the blower (Figure 3).

The foam solution flow rate and the air blower speed can be adjusted during the spraying of foam. Generally, a "wet" foam will be produced at high foam solution flow rate. A high expansion foam is usually formed at low foam solution flow rate and high air blower speed. By expansion factor is meant the ratio of the volume of foam produced to the volume of solution sprayed.

3.1.2.3 Modified Foam Generator

In previous contract work on high expansion foam, a laboratory foam generator was used for development work. It is 4-1/2 inches in diameter, uses a Fulljet nozzle (from Spraying Systems Inc. #5 Type 1/8 GG) and a 125 cfm blower and had a generating capacity much too high for this study. A new foam generator was developed for the production of a small but steady foam stream. A Foamjet nozzle (Spraying Systems Inc. #11259-U, Type 1/4 TT) with an orifice disk D-15 was modified by cutting a slot at 90 degrees to the slot in the original nozzle. This new set-up could spray foam solution at different rates up to 360 ml/min. Foams with expansion factors ranging from 50X to 400X could be made.

3.1.2.4 Newly Developed Foam Generator

By the end of this study, a foam sprayer had been developed without air blower. Foam solution entered at one side of a Fulljet nozzle and compressed air entered at the other side. No screen was used. A unique foam was produced. It had small cells but high expansion factor (over 100X).

3.1.3 EVALUATION OF POLYMERS

Three kinds of polymers were evaluated as prospective ingredients to be used in the developed foam formulation. They are gelatin, polyvinyl alcohol, and water-soluble copolymeric polyelectrolytes. Gelatin was employed successfully in water-based, limited stability foam during previous Monsanto Research Corporation work. However, for coal mine applications it might produce unpleasant odors because of putrefaction if not well preserved. It was decided it would be a prime candidate if other polymeric materials could not be used successfully.

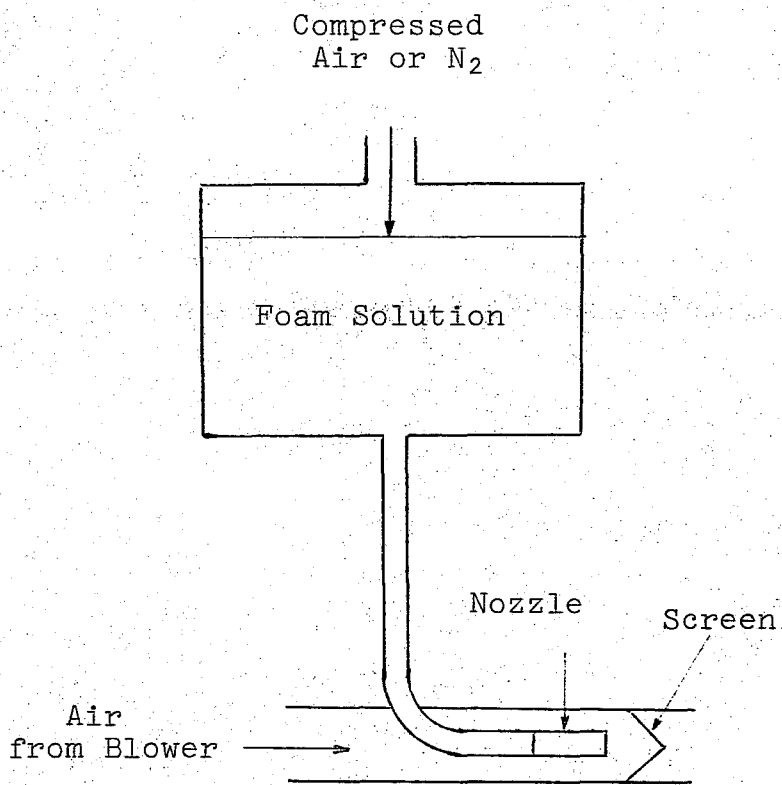


Figure 3. Schematic Drawing of the Foam Generator

Commercial polyvinyl alcohol is available in a number of grades, each differing in degree of polymerization, percent hydrolyzed, and residual acetate content. For this study, the molecular weight and water solubility of polyvinyl alcohol, its compatibility with the surfactant and the foaming performance of its solution were of interest.

Two kinds of water-soluble polyelectrolytes were selected for evaluation. One was polyacrylic acid, and the other ethylene/maleic anhydride copolymer. These polymers have utility as thickeners. Very dilute solutions of these water-soluble polyelectrolytes have very high viscosities. Thus, a very small amount of polymer will be needed for making foam solutions, if these polymers can be used for this application.

3.1.3.1 Foaming Performance

The gelatin (Swift Co's 610 type) foam was studied first. A 5 to 7.5% gelatin aqueous solution could be sprayed into foam with 15 parts by weight of Hi-Ex foaming agent per 1000 parts of gelatin solution. The foam expansion factor could be adjusted to over 500X. This foam was much too stable; it would remain in place for hours and even days.

Foam expansion factor was determined by the following procedure. An open-top cardboard box was prepared. Its weight (in grams) and volume (in ml) were determined. Foam was sprayed into the box until it was filled. Normally, it took 10 to 20 seconds to fill a box with a volume of 140,000 ml. During such a short period of time, no drainage came out of the foam in the box. The weight (in grams) of the foam-filled box was checked again. The foam expansion factor was calculated by dividing the volume of box with the weight of foam.

Initially, polyvinyl alcohol was evaluated using DuPont's Elvanol polymer. The following grades were used.

<u>Resin Grade</u>	<u>Molecular Weight</u>
51-05	low
52-22	medium
72-51	high
72-22	high
73-125	super high

To prepare the polyvinyl alcohol solution, water was first heated to 60-80°C and then the polymer was stirred into the water. The resin went into solution after 20-30 minutes. Six polyvinyl alcohol solutions were prepared. Each of these solutions was sprayed into foam with the laboratory foam generator. To every 100 parts by weight of solution, 1.5 parts of Hi-Ex were added. The foam compositions and expansion factors are listed in Table 2.

Table 2

EXPANSION FACTORS OF ELVANOL FOAMS

<u>Foam Solution Composition</u>	<u>Expansion Factor</u>
1% Elvanol 72-51	98X
1% Elvanol 72-60	90X
5% Elvanol 51-05	85X
2.5% Elvanol 51-05 + 2.5% Elvanol 52-22	65X
2.5% Elvanol 51-05 + 2.5% Elvanol 72-51	52X
4% Elvanol 51-05 + 1% Elvanol 73-125	55X

Monsanto Company's polyvinyl alcohol Gelvatol 40-10 (low molecular weight polymer) was also evaluated by spraying into foam with Hi-Ex and checking the foam expansion factor, with the following results:

Table 3

EXPANSION FACTORS OF GELVATOL FOAMS

<u>Gelvatol 40-10 Solution Concentration (%)</u>	<u>Parts of Hi-Ex per 100 parts of Solution (by vol.)</u>	<u>Foam Expansion Factor</u>
5	1.5	97X
3	1.5	97X
1	1.5	97X
1	3.0	101X
1	5.0	101X

The polyvinyl alcohol foams sprayed from aqueous solutions of high and low molecular weight polymers had relatively low expansion factors. Increased use of Hi-Ex did not increase the expansion factor. Low concentration (1%) polyvinyl alcohol solution had very low viscosity (under 1 cp) and the foam sprayed with this diluted solution was very unstable. Gelvatol 20-30 (comparable to Elvanol 51-05 in regard to solution viscosity) was used extensively in the later part of this study.

Water-soluble polyelectrolytes were then evaluated after the work on polyvinyl alcohol. Goodrite K-702, a highly pure water solution of polyacrylic acid, was made into 5% aqueous solution and sprayed into foam using 1.5 parts of Hi-Ex per 100 parts solution. The foam expansion factor was 267X. However, the foam was very unstable.

Two of Monsanto Company's ethylene/maleic anhydride copolymer resins were evaluated. They were listed as follows:

<u>Grade</u>	<u>Polymer Type</u>	<u>Structure</u>	<u>Viscosity of 2% Sol. (cp)</u>
EMA-11	Linear	Anhydride	2
EMA-54	Crosslinked	Sodium Salt	640

A 5% EMA-11 solution was prepared using 1.5 parts of Hi-Ex to 100 parts of polymer solution and sprayed into foam. The foam expansion factor was 265X.

EMA-54 is a mixture of mono- and disodium salts. A 5% EMA-54 solution was prepared. It was very viscous. Its viscosity was greatly reduced when diluted to different concentration.

<u>EMA-54 Concentration (%)</u>	<u>Viscosity (cp)</u>
1	438 at 29°C
0.5	93 at 29°C
0.2	12 at 22°C
0.1	6 at 20°C

The 0.2% EMA-54 solution was sprayed with 1.5 parts of Hi-Ex to 100 parts of solution. The expansion factor of the sprayed foam was 250X. This foam was very stable. EMA-54 was considered as a promising candidate as a foam solution ingredient mainly because only a very low concentration of EMA-54 was required for making a foam solution with optimum viscosity.

3.1.3.2 Compatibility with Surfactants

Solutions of gelatin (Type 610), polyvinyl alcohol (Gelvatol 20-30), and EMA-54 were checked for their compatibility with each of the surfactants having a contact angle ≤ 10 degrees when tested on a polished coal surface. Only the following surfactants posed no compatibility problems: DDBSA 99-B, DDBSA 99-UB, Santomerse ME-B Slurry, Emcol E-12, Kyro EOB, Poly-Tergent J-300, Sterox AJ, Tergitol TMN, and Amidox C-5.

DDBSA 99-B, DDBSA 99-UB, and Santomerse ME-B Slurry were made into solutions separately. Each of these solutions were sprayed with Hi-Ex. A pungent, sharp odor was noted when they were used. Thus, these three surfactants would not be suitable for coal mine application. Emcol E-12 is used mainly as a germicide and is a relatively expensive surfactant.

3.1.4 EVALUATION OF FOAMING AGENTS

3.1.4.1 Evaluation of Substitutes

Although Hi-Ex has been used successfully as a foaming agent in our past study work, it is a commercial proprietary formulation and is relatively expensive. Moreover, Hi-Ex does cause compatibility problems, especially with gelatin solution. Foam solution with Hi-Ex usually produced a white precipitate on standing. It was felt that an inexpensive substitute for Hi-Ex should be searched for. The following foaming agent or surfactants were evaluated.

National High Expansion Foam Liquid

Amidox C-2
Deriphat 151
Neodol 23-3A
Neodol 25-3A
Steol CA-460
Triton X-301

Each of these together with Hi-Ex were mixed with water (1.5 to 100 parts) and sprayed into foam. Neodol 25-3A (one part) was diluted with water (2 parts) in order to reduce its viscosity. Amidox C-2 did not go in solution easily at room temperature. It was not evaluated.

The expansion factors of these sprayed foams are listed in Table 4.

Table 4

EXPANSION FACTORS OF WATER-BASED FOAMS WITH VARIOUS FOAMING AGENTS OR SURFACTANTS

<u>Foaming Agent or Surfactant</u>	<u>Foam Expansion Factor</u>
Hi-Ex	137X
National High Expansion Foam Liquid	131X
Deriphat 151	215X
Neodol 23-3A	275X
Neodol 25-3A (diluted)	105X
Steol CA-460	179X
Triton X-301	231X

At least four of the six evaluated foaming agents produced foams with higher expansion factors than those with Hi-Ex.

3.1.4.2 Evaluation of Surfactants as Foaming Agent

To further economize the foam formulation, a study was made on the possibility of using a surfactant that would also function as a foaming agent. Generally, a surfactant is not necessarily a foamer. However, foaming agents are usually surfactants. Even though Hi-Ex was also shown to be a good wetting agent for coal, its cost kept it from being considered as a combined surfactant/wetting agent candidate.

To evaluate the promising coal-wetting surfactants as foaming agent, 1.5 parts of each of them were mixed with 100 parts of water and sprayed into foam. Their expansion factors were determined to be as follows.

Table 5

EXPANSION FACTORS OF WATER/SURFACTANT FOAM WITH THE SURFACTANT AS FOAMER

<u>Surfactant as Foamer</u>	<u>Foam Expansion Factor</u>
Amidox C-5	226X
Kyro EOB	253X
Poly-Tergent J-300	250X
Sterox AJ	263X
Tergitol TMN	287X
Tergitol TMN (0.5 parts)	285X

As compared to Kyro EOB, Poly-Tergent J-300 had greater wettability on coal and Sterox AJ could produce foam with higher expansion factor. Thus, Poly-Tergent J-300, Sterox AJ, and Tergitol TMN were selected as promising surfactants to be used as combined wetting and foam agents.

Tergitol TMN was shown to be the most promising surfactant/foaming agent. High expansion foam could be produced even when 0.5 parts of Tergitol TMN was used with 100 parts of water. Tergitol TMN is trimethyl nonyl polyethylene glycol ether. It contains 90% by weight of active ingredient. Its specific gravity at 20/20°C is 1.024 (8.5 pounds per gallon).

3.1.5 EVALUATION OF FOAM SOLUTIONS

3.1.5.1 Wettability on Coal

The contact angles between a coal surface and various foam solutions were determined with the following result.

Table 6

CONTACT ANGLES BETWEEN COAL SURFACE
AND VARIOUS FOAM SOLUTIONS

5% 610 Gelatin Solution (100 parts)/Surfactant (0.5 part)

<u>Surfactant</u>	<u>Contact Angle (degree)</u>
Poly-Tergent J-300	0
Sterox AJ	0
Tergitol TMN	0

5% Gelvatol 20-30 Solution (100 parts)/Surfactant (0.5 part)

<u>Surfactant</u>	<u>Contact Angle (degree)</u>
Poly-Tergent J-300	10.3
Sterox AJ	8.7
Tergitol TMN	9.5

5% Good-rite K-702 Solution (100 parts)/Surfactant (0.5 part)

<u>Surfactant</u>	<u>Contact Angle (degree)</u>
Poly-Tergent J-300	8.7
Sterox AJ	7.0
Tergitol TMN	4.7

1% EMA-54 Solution (100 parts)/Surfactant (0.5 part)

<u>Surfactant</u>	<u>Contact Angle (degree)</u>
Poly-Tergent J-300	1.3
Sterox AJ	4.7
Tergitol TMN	0

0.2% EMA-54 Solution (100 parts)/Surfactant (0.5 part)

<u>Surfactant</u>	<u>Contact Angle (degree)</u>
Poly-Tergent J-300	0
Sterox AJ	0
Tergitol TMN	0

As indicated in the above data, gelatin foam solution would be a very good candidate for coal dust suppression if its preservation problem could be solved. The prices of gelatin and EMA-54 are about the same. However, gelatin foam solution will be definitely more expensive than EMA-54 solution because 5% gelatin would have to be used in the solution whereas less than 1% EMA-54 would be enough. When Tergitol TMN was used as the wetting and foaming agent, most of these foam compositions had better wettability on coal.

3.1.5.2 Expansion Factor

Foams were produced with different polymer solutions and different surfactants. Their expansion factors were as follows:

Table 7

EXPANSION FACTORS OF FOAMS OF VARIOUS COMPOSITIONS

5% 610 Gelatin Solution (100 parts)/Surfactant (0.5 part)

<u>Surfactant</u>	<u>Foam Expansion Factor</u>
Poly-Tergent J-300	296X
Sterox AJ	296X
Tergitol TMN	337X

5% Gelvatol 20-30 Solution (100 parts)/Surfactant (0.5 part)

<u>Surfactant</u>	<u>Foam Expansion Factor</u>
Poly-Tergent J-300	208X
Sterox AJ	183X
Tergitol TMN	120X

5% Good-rite K-702 Solution (100 parts)/Surfactant (0.5 part)

<u>Surfactant</u>	<u>Foam Expansion Factor</u>
Poly-Tergent J-300	270X
Sterox AJ	248X
Tergitol TMN	243X

Table 8

EXPANSION FACTORS OF FOAMS FROM EMA-54 SOLUTIONS OF VARIOUS CONCENTRATIONS

EMA-54 Solution (100 parts)/Surfactant (0.5 part)

<u>Surfactant</u>	<u>Foam Expansion Factors at Various EMA-54 Conc.</u>			
	<u>1%</u>	<u>0.75%</u>	<u>0.5%</u>	<u>0.2%</u>
Poly-Tergent J-300	81X	120X	182X	-
Sterox AJ	53X	71X	116X	-
Tergitol TMN	81X	131X	206X	310X

The gelatin foam had the highest expansion factor of the compositions tested. With EMA-54 solutions, Tergitol TMN always produced foams with highest expansion factor.

3.1.5.3 Effects of Water Hardness and pH

An artificial hard water was prepared by dissolving 5 grams of CaO in 3000 ml of Dayton city water. Compressed CO₂ was bubbled through this solution with stirring for 30 minutes. The precipitate was filtered out. This "synthetic hard water" and three other waters were used to prepare 0.5% EMA-54 solutions. No difficulty was experienced in making these solutions. Their properties are as follows:

Table 9

PROPERTIES OF 0.5% EMA-54 SOLUTIONS PREPARED WITH DIFFERENT KINDS OF WATER

<u>Water Type</u>	<u>Dissolved Solids (ppm)</u>	<u>Solution pH</u>	<u>Solution Viscosity (cp at 22°C)</u>
Synthetic hard water	-	8	22
Dayton city water	242	7	62
Deionized water	6	7	258
Distilled deion- ized water	<0.5	7	270

The viscosity of the EMA-54 solution became higher as the hardness of water was reduced. Each of these solutions was sprayed with Tergitol TMN (0.5 parts per 100 parts of solution), using a modified laboratory foam generator. The results were as follows:

Table 10

EXPANSION FACTORS OF FOAMS OF 0.5% EMA-54 SOLUTIONS IN DIFFERENT KINDS OF WATER

<u>Water Type in Foam Solution</u>	<u>Foam Expansion Factor</u>
Synthetic hard water	236X
Dayton city water	211X
Deionized water	184X
Distilled deionized water	153X

Thus, the expansion factor of EMA-54/Tergitol TMN foam was lower when more pure water was used in the foam solution. This reduced expansion factor was probably due to the higher viscosity of these solutions.

EMA-54 solutions (0.5%) were also prepared with water of different pH (regulated by adding HCl or NaOH to Dayton city water). The solution properties were determined as follows:

Table 11

PROPERTIES OF 0.5% EMA-54 SOLUTIONS
IN WATER OF DIFFERENT PH

<u>Water pH</u>	<u>Solution pH</u>	<u>Solution Viscosity</u> (cp @21°C)
4	6	33
6	7-8	70
8	7-8	170
10	7-8	172

Each of these solutions was sprayed with Tergitol TMN (0.5 part per 100 parts solution) using a modified laboratory foam generator. The following results were obtained.

Table 12

EXPANSION FACTORS OF FOAMS OF 0.5% EMA-54 SOLUTIONS
IN WATER OF DIFFERENT PH

<u>Water pH in Solution</u>	<u>Foam Expansion Factor</u>
4	200X
6	160X
8	120X
10	120X

It appeared that the pH values of EMA-54 solutions made with water of different pH tended to approach the 7-8 range. However, foam of higher expansion factor was produced from solution made with the more acidic solutions.

3.1.6 RECOMMENDED FOAM FORMULATIONS

As a result of the research on foam solutions, a promising foam formulation was developed. It wetted down the coal dust and produced foams of varied expansion factors. This foam had limited stability and was inexpensive. The generalized formulation was as follows:

Water
Polymer (EMA-54)
Wetting agent/foaming agent (Tergitol TMN)

The concentration of EMA-54 in the solution could be varied from 0.1 to 1%. Tergitol TMN was used as a wetting agent and as a foaming agent. To every 100 parts by volume of polymer solution, 0.5 parts of Tergitol TMN should be added to furnish enough foamability as well as coal dust wettability.

The expansion factor of the foam produced from this foam formulation could be adjusted by varying either the EMA-54 concentration or the spraying conditions (feeding rate of the solution; air blower speed), as listed in the following table.

Table 13

EXPANSION FACTOR RANGES OF FOAMS OF EMA-54 SOLUTIONS
OF VARIOUS CONCENTRATIONS

<u>EMA-54 Concentration</u>	<u>Foam Expansion Factor Range</u>
0.1%	22X - 400X
0.3%	62X - 252X
0.5%	49X - 267X

Dr. William H. Hunt, Toxicologist of the Medical Department, Monsanto Company, classed EMA-54 as practically non-toxic and non-irritating. However, it was advised that repeated and prolonged skin contact be avoided, and as a hygienic procedure, the polymer should be washed off with soap and water. In case of accidental eye contact it should be flushed out with water.

According to Union Carbide Corporation's bulletin "Tergitol Surfactants", Tergitol TMN does not cause primary skin irritation in rabbits 24 hours following application of .01 ml of pure Tergitol to uncovered skin. A 5% Tergitol TMN aqueous solution may cause serious injury in the rabbit's eye. However, when the Tergitol TMN concentration is reduced to 0.5% or less, its toxicity is greatly reduced. When handling concentrated Tergitol TMN, gloves and goggles should be used. The handling of concentrated Tergitol solution requires precaution, but at the low concentration used in producing foams they are not particularly hazardous.

The price of EMA-54 was quoted by Monsanto Company on 16 April 1970, F.O.B. Texas City, Texas, as follows:

<u>EMA-54</u>	<u>20,000 lb T/L</u>	<u>2,000 lb to T/L</u>	<u>Standard Bag to 2,000 lbs</u>	<u>Less than Std. Bag</u>
Per lb	85¢	90¢	\$1.00	\$1.25

The standard container is a 50-lb net fiber drum.

The price of Tergitol TMN was quoted by Union Carbide Corporation on 20 April 1970 as follows, F.O.B. shipping point, freight allowed:

Tergitol Nonionic TMN

4,000 gallons	\$0.255/lb
TL Drum	\$0.275/lb
LTL Drum	\$0.285/lb
5 gallons	\$0.45/lb
1 gallon	\$0.85/lb

Drums contain 450 lb net and are non-returnable.

3.2 DEVELOPMENT OF A LABORATORY COAL MINING MODEL

3.2.1 Selection of Simulation Method

The selection of a meaningful laboratory test to demonstrate the effectiveness of foam in suppressing airborne respirable coal dust was a difficult one. Our approach to this problem was based on the following consideration.

- (1) It is believed that to be effective the foam must trap the dust particle as it is formed by fracture of the coal. If the dust particle ever has a chance to become airborne, it would be very difficult for the foam to trap the particle. The particle, being very light, would probably be displaced by the foam front and remain airborne.
- (2) The coal dust should be freshly formed at the time it is trapped by the foam. Previously ground coal dust, having a very large surface area, would be subject to rapid oxidative attack by the oxygen in the air. Once this occurs, the surface is no longer the same chemically as the freshly fractured surface. The response of the two types of coal surface (freshly formed and oxidized) to surfactants might be entirely different. A foam formulation that would behave well toward pre-ground coal that has had extensive surface oxidation, might not adequately wet freshly formed coal dust particles.
- (3) The method of forming the coal dust should simulate as nearly as possible, on a laboratory scale, the cutting action of a continuous miner or other coal cutting machine.

With these objectives defined, a testing procedure had to be devised that would permit us to test the effect of foam on respirable dust. Several suggestions were made as to methods of generating the coal dust.

- (1) The use of a grinding wheel working against the face of a block of coal. This suggested approach, while it offered the possibility of producing large amounts of dust, was discarded because of the tendency for grinding wheels to load up with the material being cut.
- (2) The use of a chain saw cutting through a block of coal. This approach would have simulated the action of a cutting machine. However, because of the high cutting rates of chain saws, an excessive amount of coal would have been used. More serious would have been the problem of controlling the rate and the depth of cut using a saw.
- (3) The use of a horizontal boring mill using a fly cutter was proposed as simulating the action of a continuous miner's picks. This approach offered the possibility of controlling the rate of cutting and the depth of cut taken. These features were inherent in a boring machine with its controls for rate of feed, depth of cut, variable speed of revolutions of the cutter, and controls for positioning the block of coal with respect to the cutter. The blades of the fly cutter simulate to some degree the action of the picks of the continuous miner. However, the cutter blades have a shaving or cutting action opposed to the gauging or digging action of the picks of the miner.

The alternatives were considered and it was decided that the use of a horizontal boring mill offered the best chance of simulating, on a miniature scale, the action of a continuous miner.

A suitable used boring mill was purchased and moved to our laboratories and installed. This machine was a Lucas Machine Tool, 3-inch horizontal boring mill fitted with a 5 H.P. motor. After receipt it was fitted with a 4-1/2 inch fly cutter which had six cutters. Subsequent to installation, suitable hold downs for the blocks of coal, which were to be cut, were developed and installed. A hood for containment of dust around the coal was fabricated and a duct installed to transport and dust and provide a place for mounting sampling tubes.

3.2.2 General Layout

The laboratory coal mining model was assembled with three components (Figure 4). A 3 inch horizontal boring machine was employed as the coal dust generator. A six-blade flycutter was attached to the shaft of the machine. The cutter was set to revolve counterclockwise against a large lump of coal clamped onto the table of the machine. This arrangement simulated the coal mining by a "miniature" continuous miner (Figures 5 and 6).

The coal dust sampling system consisted of a partly enclosed chamber around the coal cutting area. Inside this chamber was a duct opening (4 in. x 12 in.) as the intake of coal dust. It could be adjusted forward and backward with the connecting flexible pipe (Flexflyte Type VF reinforced fabric duct). Two sampling copper tubes (3/8 in. outside diameter) were installed with their collecting ends located at the center of the collection duct outside the chamber. Sampling tube A (Figure 7) was 60 inches from the chute opening and sampling tube B was 26 inches from tube A. The draft within the duct was induced by a roof exhaust fan. The air flow rate at the center of the duct was adjusted to 100 ft/min. as checked by an Alnor Velometer. Originally a segment (ca. 20 inches) of Plexiglas pipe was a part of the 8-inch diameter pipe duct. It was installed to afford visibility in the duct. Later, it was removed in order to make sure that the coal dust stream inside the duct would not be affected by possible static electrical charges built up on the plastic duct.

3.2.3 Coal Dust Generation

As shown in Figure 8, a large lump of coal was clamped on the table (42 in. x 22 in.) of the boring machine. The cutter could cut the coal in two directions, either side A by moving along the ab directions, or side B by remaining stationary with the coal pushed forward past the cutter by the moving table.

The traveling range of the cutter was 20 inches. It could be adjusted to revolve at different speeds. At 180 rpm, the automatic feeding (traverse) speed range was 3/4 to 14 in. per minute. The corresponding feeding speed range of the table was 3/4 to 14.5 in. per minute. At speeds less than 180 rpm all these feeding speeds were reduced proportionally. Both the cutter and the table could also be fed manually.

To produce coal dust of respirable size range, the cutting depth of the coal was kept small. At first, coal dust was produced at a cutting depth up to 0.04 in. The corresponding coal dust concentration was 10 million particles per cubic foot (mppcf) level. Later, a study was carried out on the production of more coal dust with the boring machine. Two sets of experiments were performed. One set was done to determine how much coal, too coarse to become airborne, was cut

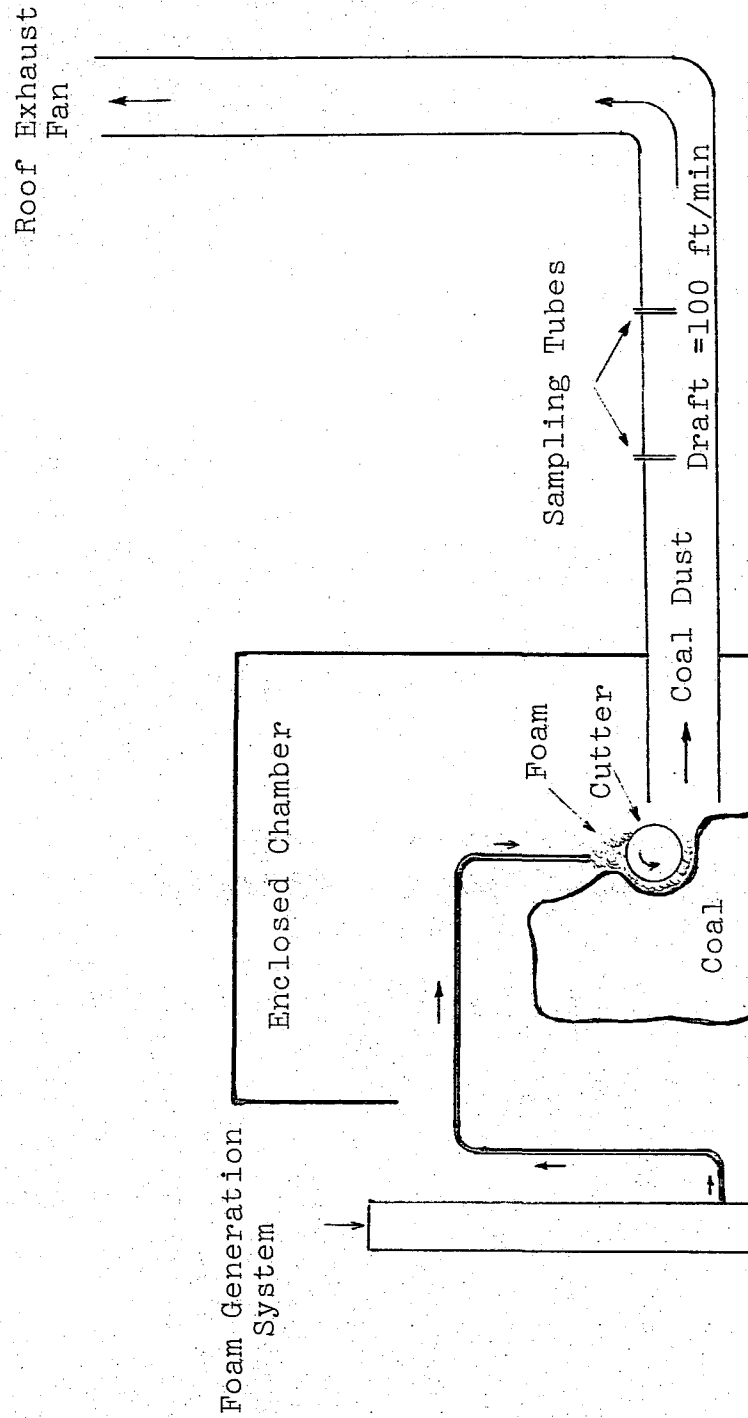


Figure 4. Schematic Layout of the Laboratory Coal Mining Model

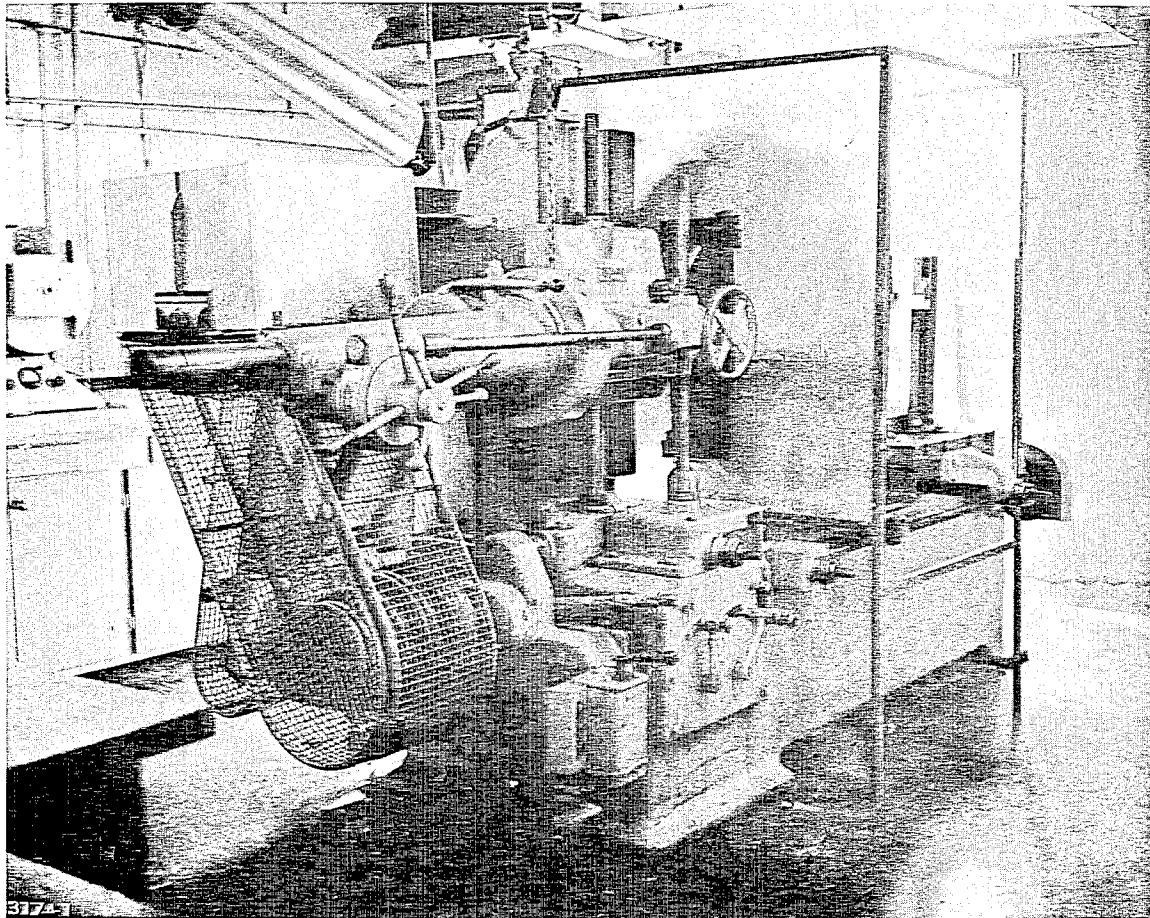


Figure 5. Horizontal Boring Machine

NOT REPRODUCIBLE



Figure 6. Coal Cutting

NOT REPRODUCIBLE

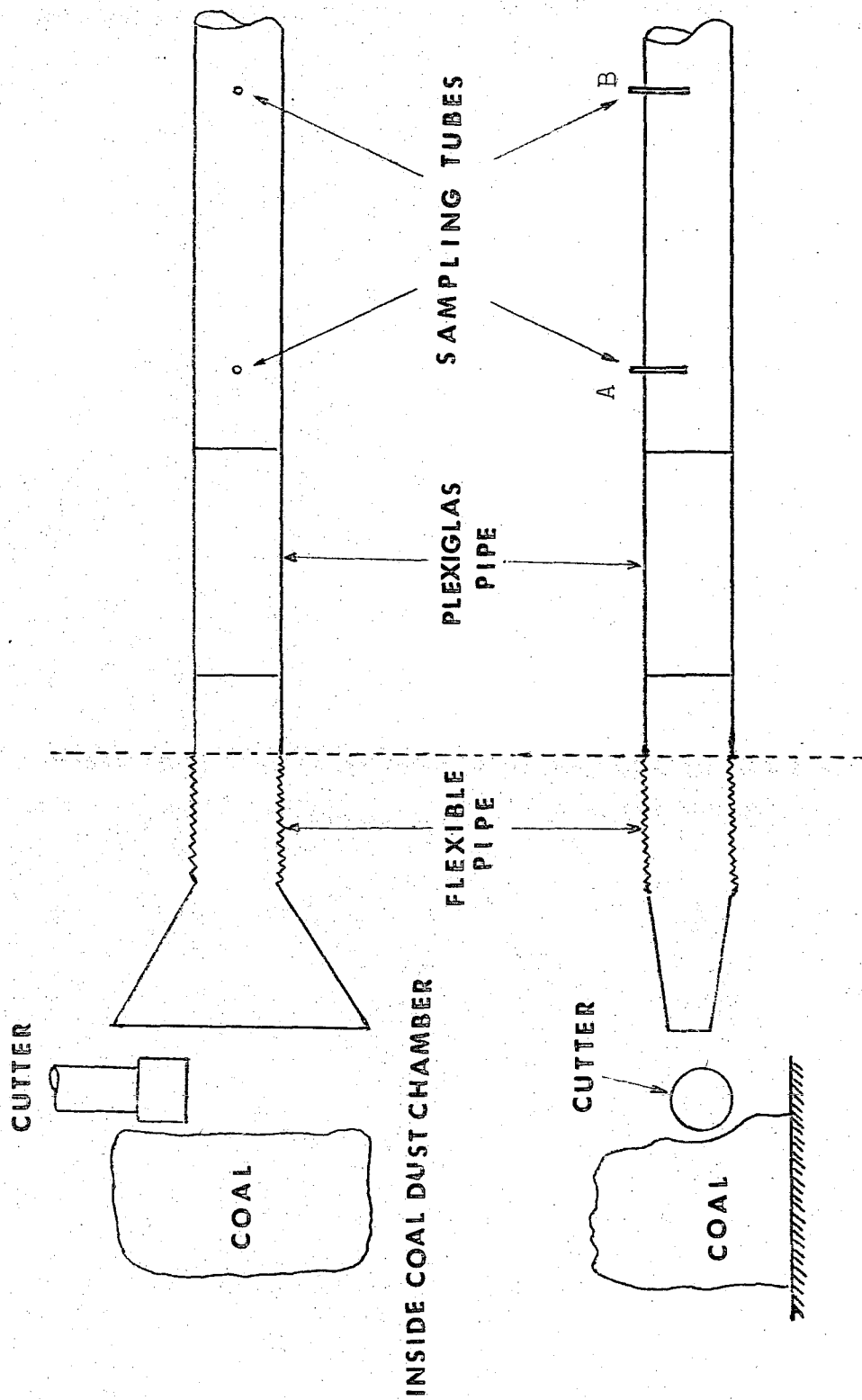


Figure 7. Top View (above) and Elevation (below) of the New Coal Dust Sampling System

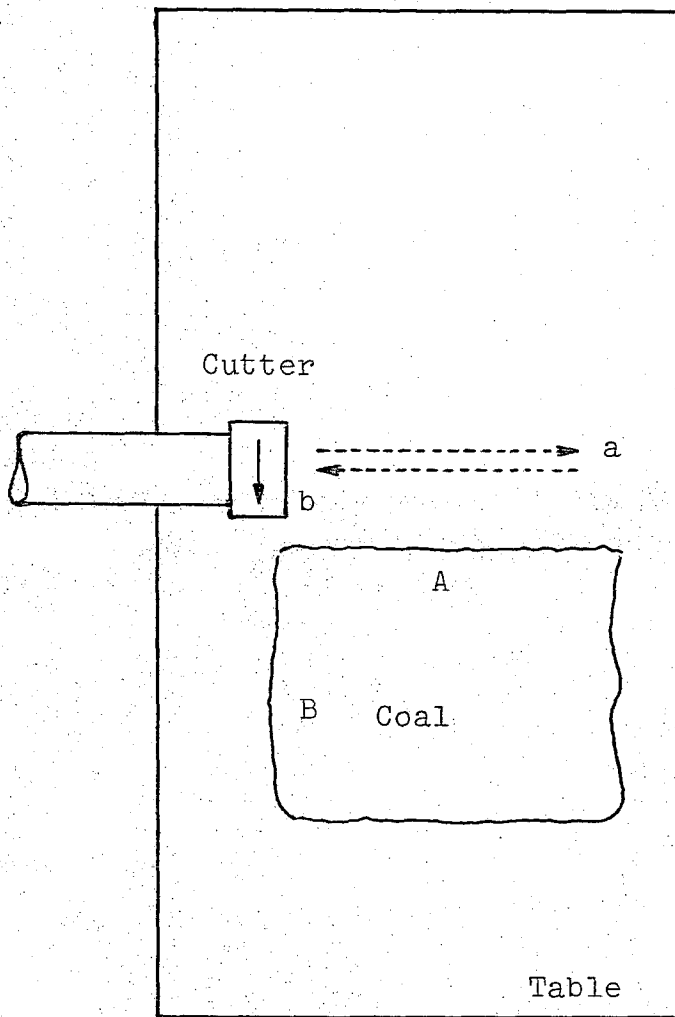


Figure 8. Top View Sketch of the Coal Cutting Arrangement

per pass of the cutter. The conditions were varied to determine under what conditions the largest amount of fines had a chance of being produced. This work was done in collaboration with Professor J. Outwater (a Monsanto Research Corporation consultant) from the University of Vermont.

The coal which did not become airborne was collected on a paper placed immediately below the cutter. The results were the following:

Table 14

COAL DUST GENERATION EXPERIMENT DATA

<u>Speed of Cutter (rpm)</u>	<u>Traverse Speed (in./min)</u>	<u>Depth of Cut (in.)</u>	<u>Calculated Coal Cut (g)</u>	<u>Coarse Coal Collected (g)</u>	<u>Fine Coal by Difference (g)</u>
60	1-1/8	0.04	55	34	21
60	14	0.04	55	17	38
180	1-1/8	0.04	55	17.5	37.5
180	14	0.04	55	12	43
60	14	0.08	110	53	57
180	14	0.08	110	25.5	84.5

When the traverse speed was 1-1/8 in./min. it took 10 minutes to cross the coal face by the traveling cutter. When the rate was increased to 14 in./min. it took less than one minute to cross the face. Based upon these data, the approximate rates of fine coal production were calculated as follows:

Table 15

CALCULATED AMOUNTS OF COAL DUST
PRODUCED UNDER DIFFERENT CUTTING CONDITIONS

<u>Speed of Cutter (rpm)</u>	<u>Traverse Speed (in./min)</u>	<u>Depth of Cut (in.)</u>	<u>Fine Coal Production (approximate g/min)</u>
60	1-1/8	0.04	2.1
60	14	0.04	>38
180	1-1/8	0.04	3.8
180	14	0.04	>43
60	14	0.08	>57
180	14	0.08	>84.5

From the above data, it became apparent that the chance of producing large amounts of coal dust would be increased at high cutter speed, high traverse speed, and increased depth of cut.

Another set of experiments was performed with results confirming the findings of the first set of experiments. Coal dust samples were generated at different cutter speeds, traverse speeds, and cut depths. The particle count data of these samples are listed below:

Table 16

INCREASED PRODUCTION OF COAL DUST

<u>Speed of Cutter (rpm)</u>	<u>Traverse Speed (in./min)</u>	<u>Depth of Cut (in.)</u>	<u>Airborne Particle (mppcf)</u>
60	1-1/8	0.04	2.96
180	1-1/8	0.04	8.80
180	1-1/8	0.02	6.00
180	14	0.02	17.60
180	14	0.04	38.86
180	14	0.06	56.00
180	14	0.08	70.44
180	14	0.09	63.48
180	14	0.10	62.96

The coal dust concentration data with traverse speed of 14 in./min are plotted in Figure 9. It appeared that maximum fine coal dust production could be achieved at a depth of cut of about 0.08 in. Further increase in cut depth resulted in reduced rates of dust production.

3.2.4 Coal Dust Sampling

The coal dust sampling system was described earlier (Figure 6). At first, a MSA Midget Impinger hand-operated vacuum pump was used to apply suction to the impinger unit. Later, a laboratory vacuum pump was used instead, with the arrangement sketched in Figure 10. The system was adjusted to give a vacuum equal to 12 inches of water.

A general procedure was established for coal dust sampling. N-propanol was filtered with Millipore 0.25 microns, 47 mm diameter, UGWP 04700 filter paper. The solvent-resistant filter paper was mounted in a Millipore XX1004700 pyrex filter holder. The impinger units were cleaned with water and then with deionized water. Finally, they were cleaned with the filtered n-propanol.

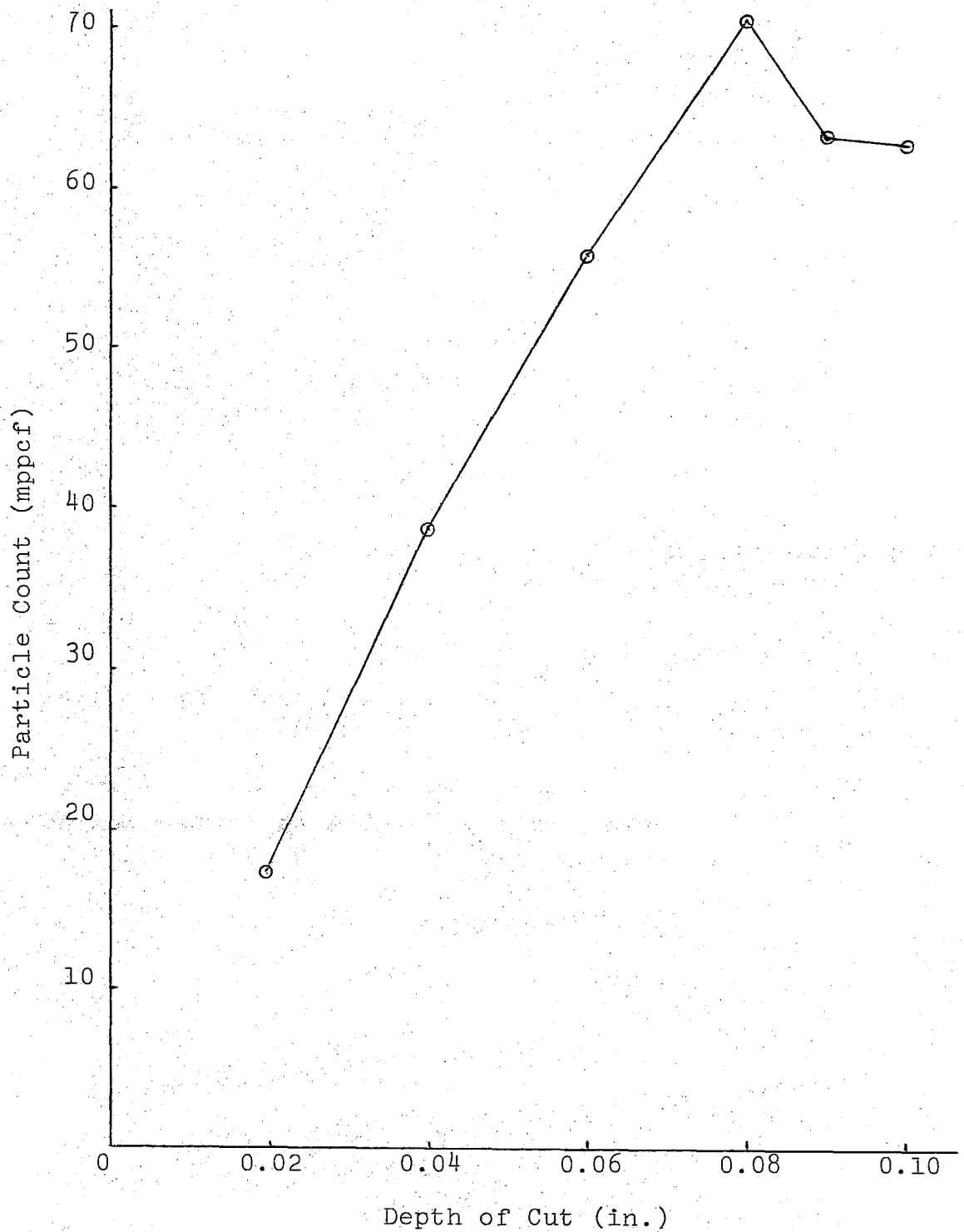


Figure 9. Depth of Coal Cut vs Particle Count

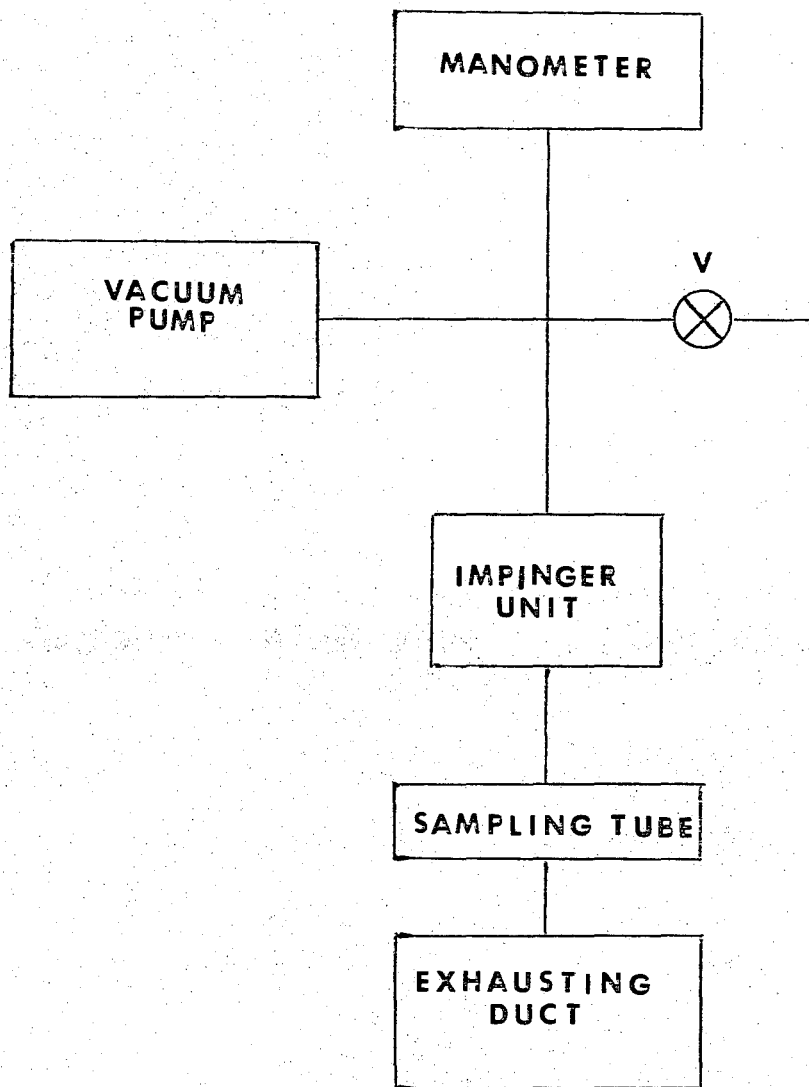


Figure 10. Schematic Drawing of the Vacuum Pump Coal Dust Sampling Device

Ten ml of the filtered n-propanol were added to each impinger unit. After the coal dust sampling system was properly connected, the boring cutter was positioned and prepared to cut coal. As soon as the cutter touched the coal the vacuum pump was turned on. Air from the exhausting duct was bubbled through the n-propanol in the impinger. Usually, a 5-minute sample was taken. A stop watch was used for the timing. The sample was transferred to a 30-ml bottle that had been cleaned carefully.

3.3 COAL DUST SUPPRESSION EXPERIMENTS

Preliminary tests were run to check the effectiveness of foam application in coal dust suppression. Four 5-minute samples were taken; two during coal dust generation, and two during foam application. The cutter setting was 180 rpm at 1-1/8 in./min traverse speed. The depth of cut was 0.04 inches. Foam was sprayed with a modified foam generator from a solution consisting of 1000 parts by weight of 0.5% EMA-54 aqueous solution and 5 parts of Tergitol TMN.

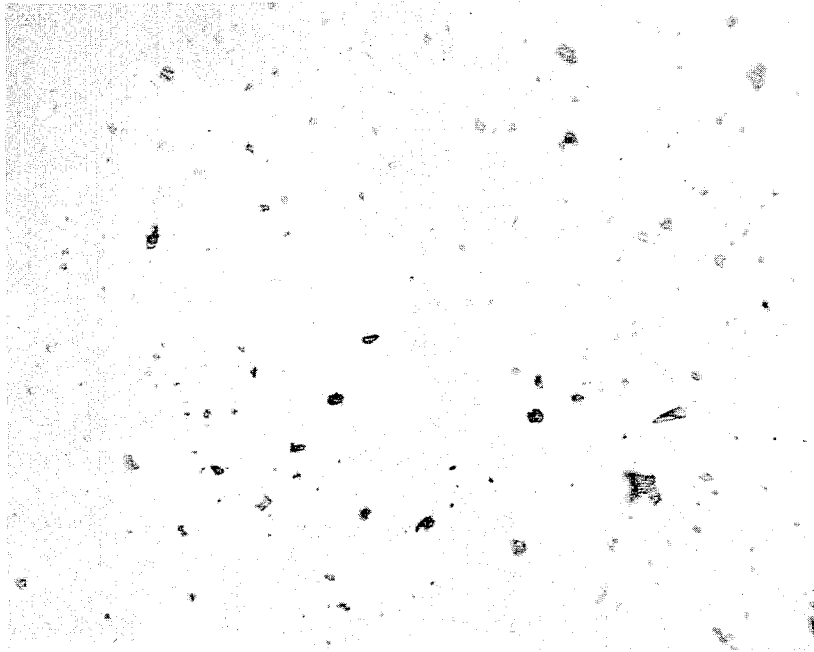
Photomicrographs were taken on these four samples with 235X magnification by the following procedures. Each of the samples was filtered with Millipore 0.22 micron, 47 mm diameter, GSWP 04700 filter paper. A small piece (ca. 1/2 in. x 1/4 in.) of the filter paper was cut off from each filtered sample. It was laid on a slide and rendered transparent by soaking with immersion oil. From the samples taken during foam application, a portion of filter paper with a high concentration of particles was deliberately selected. Quite a few particle images were due to dirt or residual dust in the microscope's optical system. Nevertheless, from Figures 11 and 12, it is evident that coal dust was greatly suppressed by foam during this test. A blank sample was collected during later tests.

3.3.1 Coal Dust Suppression Test at Low Coal Dust Concentration

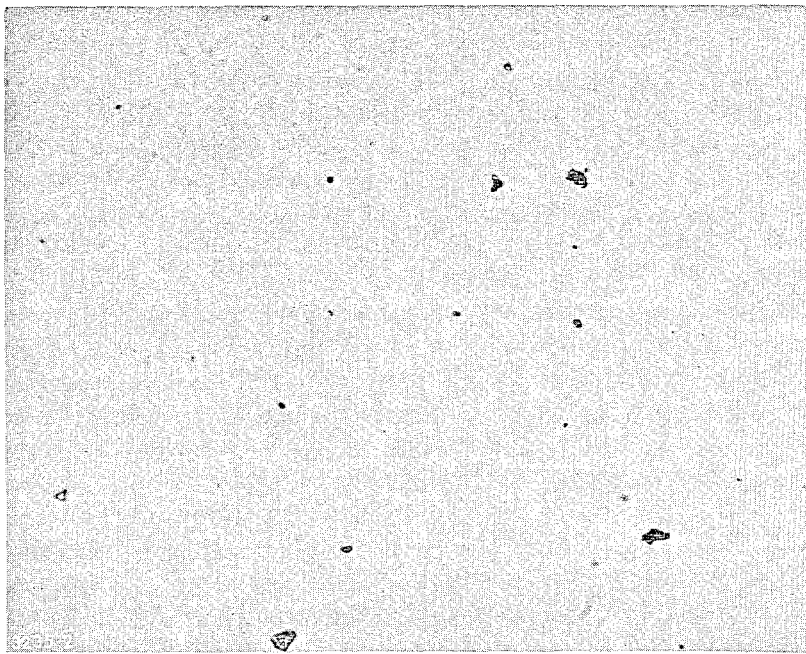
The early tests were run at low rates of coal dust generation. Three runs were performed. Coal dust samples were taken with the vacuum pump at 12 inches H₂O vacuum. In each impinger unit, 10 ml of filtered n-propanol were used as collecting liquid. Each sample was taken for 5 minutes from the exhausting duct with a draft of 100 ft/min air flow. Duplicate samples were taken for each run.

Coal dust was generated with the laboratory coal mining model with the following settings: cutter speed, 180 rpm; traverse speed, 1-1/8 in./min; coal cut depth, 0.04 inch (Run A and Run B), 0.08 inch (Run C).

The following suppression agents were used: (a) foam (1000 parts of 0.5% EMA-54 solution and 5 parts of Tergitol TMN), (b) foam (1000 parts of water and 5 parts of Tergitol TMN), (c) spray (1000 parts of water and 5 parts of Tergitol TMN), and (d) spray (water).



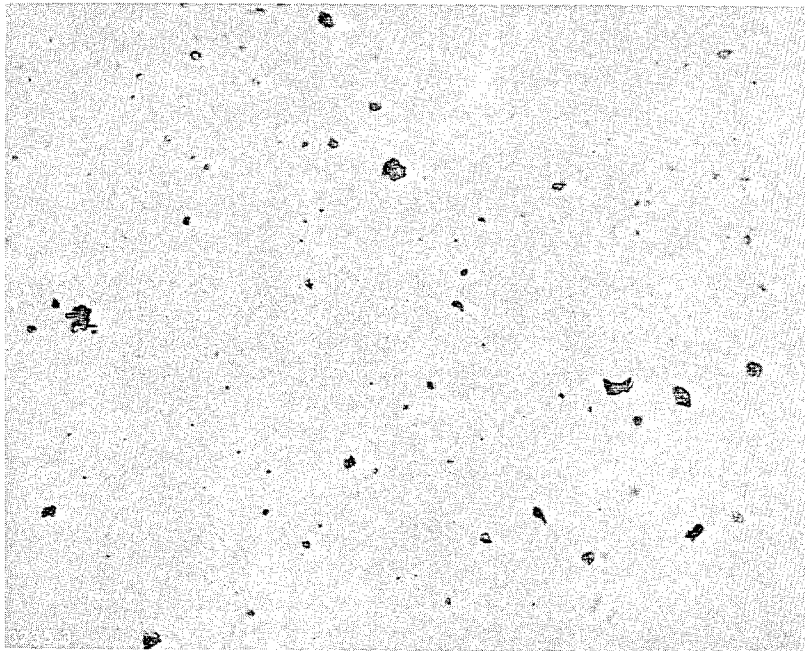
X235



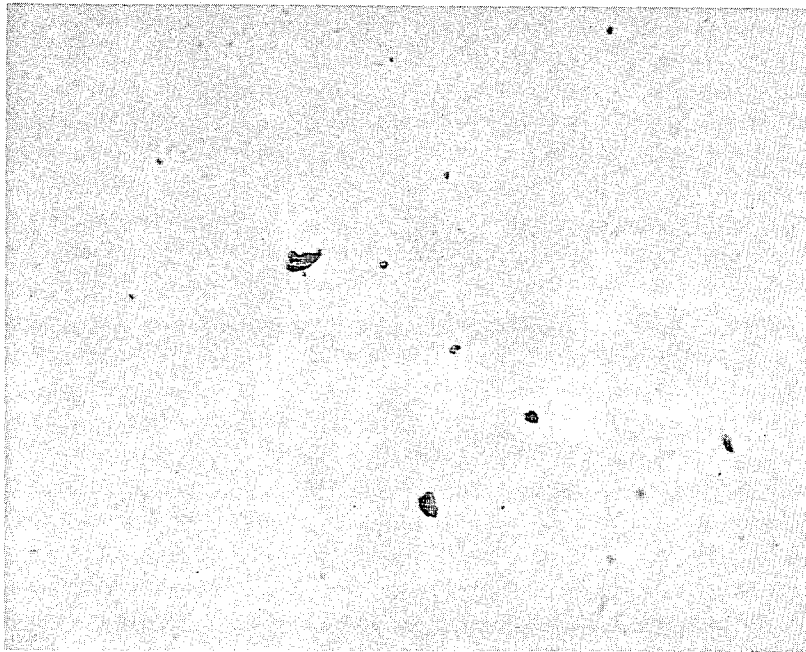
X235

NOT REPRODUCIBLE

Figure 11. Photomicrographs of Coal Dust Samples Collected by Midget Impinger (a) Before and (b) During Foam Application



X235



X235

NOT REPRODUCIBLE

Figure 12. Photomicrographs of Coal Dust Samples Collected by Vacuum Pump Method (a) Before and (b) During Foam Application

Samples were checked for their particle counts with the following results. (Table 17).

Table 17

RESULTS OF COAL DUST SUPPRESSION EXPERIMENT
AT LOW COAL DUST CONCENTRATION

Coal Dust Sampling Conditions	Particle Count (mppcf)		
	A	B	C
Blank	0.24	-	-
Coal dust sample	7.40	10.40	8.20
During H ₂ O/EMA-54/Tergitol TMN foam application	<0.32	0.32	0.80
During H ₂ O/Tergitol TMN foam application	0.32	0.64	0.96
During H ₂ O/Tergitol TMN spray	2.40	0.64	2.80
During water spray	1.60	5.50	3.40

One particle count reading of the sample taken during H₂O/EMA-54/Tergitol TMN foam application (Run A) was very low (very close to zero). Both the H₂O/Tergitol TMN spray and the water spray were applied as a very fine mist, almost a fog. In Run C, even with an increased depth of cutting (0.08 in.), the coal dust concentration was not as high as desired. This was due to the slow traverse speed.

3.3.2 Coal Dust Suppression Test at High Coal Dust Concentration

To compare more closely to actual coal mine operations, coal dust suppression tests were run at high coal dust concentration. Two series of experiments were carried out; one at different levels of coal dust concentration and the other with different amounts of foam. At the beginning, the effectiveness of foam application was judged by visual observation. It was noticed that the effectiveness of foam would be enhanced by applying foam to the cutter prior to its coal cutting action.

The first series of three coal dust samples were taken during foam application under the following conditions.

Boring Machine Setting:

- Cutter speed - 180 rpm
- Cutter feed (traverse) speed - 14 in./min
- Coal cutting depth - Run 1- 0.04 in., Run 2- 0.06 in.
Run 3- 0.08 in.

Coal Dust Sampling Condition:

- Air flow rate in sampling duct - 100 ft/min
- Volume of n-propanol in each impinger - 10 ml
- Vacuum applied - 12 in. water

Foam Solution Composition:

Water - 996 parts by weight
EMA-54 - 4 parts
Tergitol TMN - 5 parts

These samples, as well as the three corresponding coal dust samples (listed in Table 2), were checked for particle count with the results listed in Table 18.

Table 18

PARTICLE COUNT DATA OF COAL DUST SAMPLES
TAKEN BEFORE AND DURING FOAM APPLICATION
COAL DUST PARTICLE COUNT (mppcf)

<u>Run No.</u>	<u>Without Foam</u>	<u>During Foam Application</u>	<u>Foam Solution Used (ml)</u>
1	38.86	4.8	320
2	56.00	1.6	280
3	70.44	0.5	290

The second series of tests were carried out under the following conditions.

Boring Machine Setting:

Cutter speed - 180 rpm
Cutter feed (traverse) speed - 14 in./min
Coal cutting depth - 0.08 in.

Coal Dust Sampling Condition:

Air flow rate in exhausting duct - 100 ft/min
Volume of n-propanol in each impinger - 10 ml.
Vacuum applied - 12 inches water

Foam Solution Composition:

Water - 996 parts by weight
EMA-54 - 4 parts
Tergitol TMN - 5 parts

A series of four runs were performed with different amounts of foam used. The samples were checked for their particle count data. As compared to the coal dust concentration (70.44 mppcf) without foam application, the % coal dust suppressed were calculated at different amounts of foam applied. The results are listed in Table 19.

Table 19

PERCENT COAL DUST SUPPRESSED WITH DIFFERENT AMOUNTS OF FOAM

<u>Foam Solution Used (ml)</u>	<u>Particle Count (mppcf)</u>	<u>Coal Dust Suppressed (%)</u>
35	11.2	84
110	11.2	84
160	7.9	89
295	3.2	95

These data are plotted in Figure 13. It appears that even if a small amount (35 ml and 110 ml) of foam were used, a substantial reduction (84%) of coal dust could be achieved. As shown in Figure 13, when the amount of foam solution was above 110 ml, the coal dust suppression became even more effective.

3.3.3 EMA-54/Tergitol Solution as a Binder for Coal Dust

As discussed before, EMA-54 serves as a strengthening, or toughening, agent in the foam composition. It constitutes the "body" of the water-based foam. Also, it may function as a binder of coal dust. Once coal dust is wetted down, a cake will be formed so that the dust particle would not be so easily reaerosolized. This was evidenced by the following tests.

Simple experiments similar to ASTM Standard Method of Test for Oil Absorption (D-1484-60) was carried out. To each of five 50 ml beakers (labeled as A,B,C,D,E), 2 grams of coal dust were added. A mixture of water (995 parts)/EMA-54 (5 parts)/Tergitol TMN (5 parts) was prepared. Into these beakers A,B,C,D,E, 0.2 ml, 0.4 ml, 0.6 ml, 0.7 ml, and 0.8 ml of this mixture were added, respectively. The contents of each beaker were "kneaded" into a single lump. After 4 weeks, the content in beaker E still held together very well. When the beaker was tapped with a stainless steel spatula, no coal dust particles separated from the cake.

A similar experiment was also done with a mixture of water (1000 parts/Tergitol TMN (5 parts). This time, when the beaker with 0.8 ml of this mixture and 2 grams of coal dust was tapped, coal dust particles came off the kneaded lump immediately.

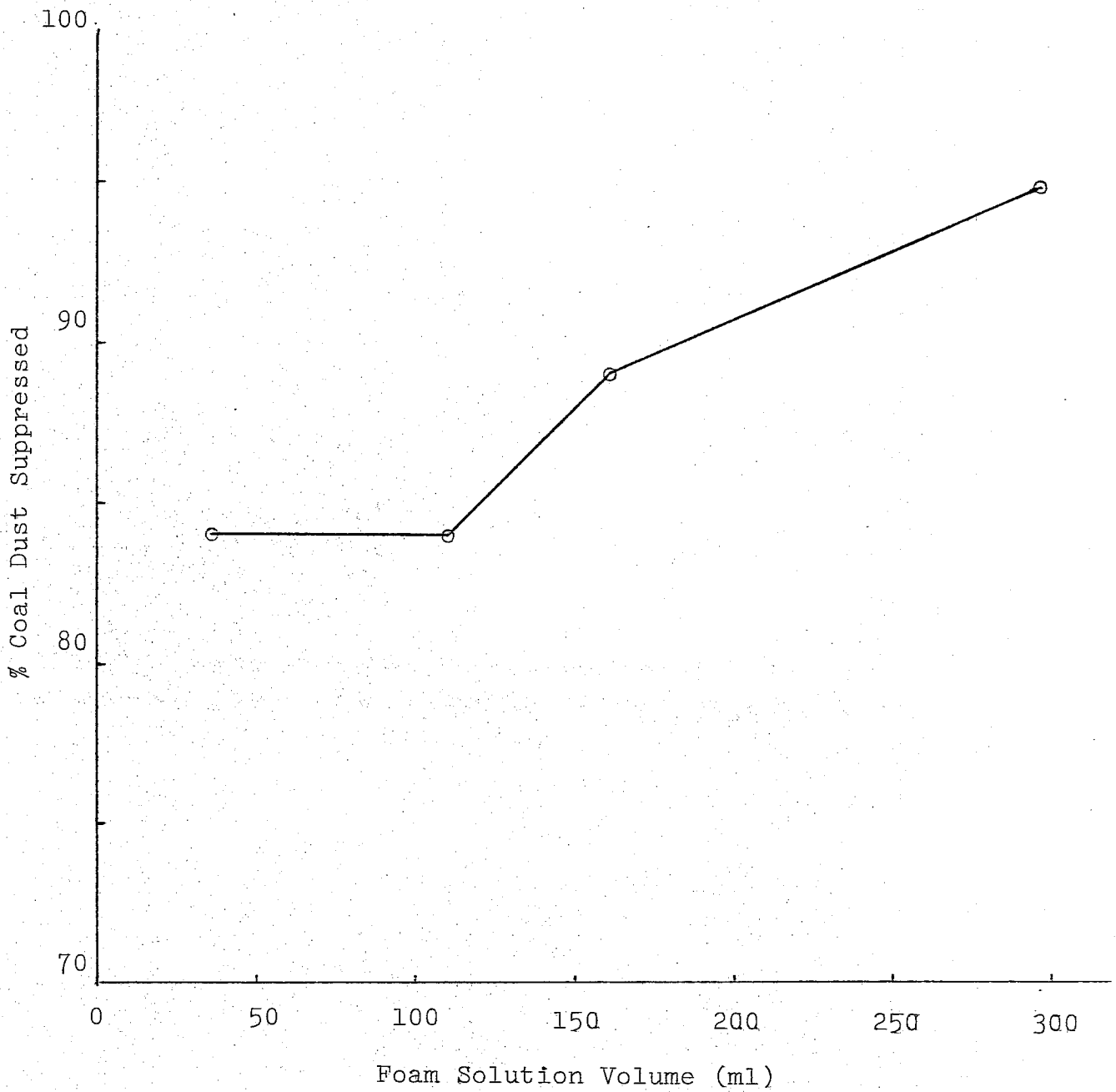


Figure 13. Percent Coal Dust Suppressed with Various Amount of Foam

3.4 ANALYSIS OF COAL DUST SAMPLE

Coal dust samples were analyzed for particle count and particle size distribution. The coal dust concentration was expressed by particle count, and the dust size range was checked by particle size distribution. Since the sampling time in this laboratory work (5 minutes or less) was much less than sampling time in coal mine tests, the total dust collected was also less. Thus, no dilution was required for the samples taken from the coal dust suppression tests, in order to give a practical sample for counting and sizing work.

3.4.1 Particle Count Determination

The procedure used for particle counting essentially followed the methods of Anderson (Ref. 2), except that a Metals Research Corp. Quantimet quantitative television microscope (Q.T.M.) was used in place of a micro-projector.

In the QTM (Ref. 3), a microscope projects an image onto the screen of a television camera (Figure 14). The electrical output from this camera passes into a closed-circuit television monitor to provide a television image, and also into a detector unit where signals from the camera emanating from the features that need to be measured are discriminated and selected from the rest of the signal. The output from the detector, consisting of pulses from the detected features, can be fed into the monitor so that the operator can see which features he has detected, and into the computer which can be set to measure the percentage area, the number of detected features, their total projection, and size distribution. All these measurements are read out on the meter on the front of the instrument.

For the coal dust measurements, the microscope was fitted with a 10X, 0.25 N.A. objective and a 1.3 N.A. Abbe condenser. Köhler illumination was used with the iris diaphragm closed to produce sufficient contrast for the small particles to be seen.

The measuring field of the QTM was adjusted to 0.25 mm x 0.20 mm to produce a measuring area of 0.05 mm². A Sedgewick-Rafter counting cell was filled with a representative portion of the sample from the midjet impinger. The particles were allowed to settle for 30 minutes. At the end of this time only the particles which were on the bottom of the cell were measured. All the particles were counted in five 0.05 mm² fields taken near each corner and at the center of the Sedgewick-Rafter cell.

The dust concentration was calculated from the formula:

$$D.C. = \frac{C \cdot 20 \cdot V}{1000 \cdot A_t}$$

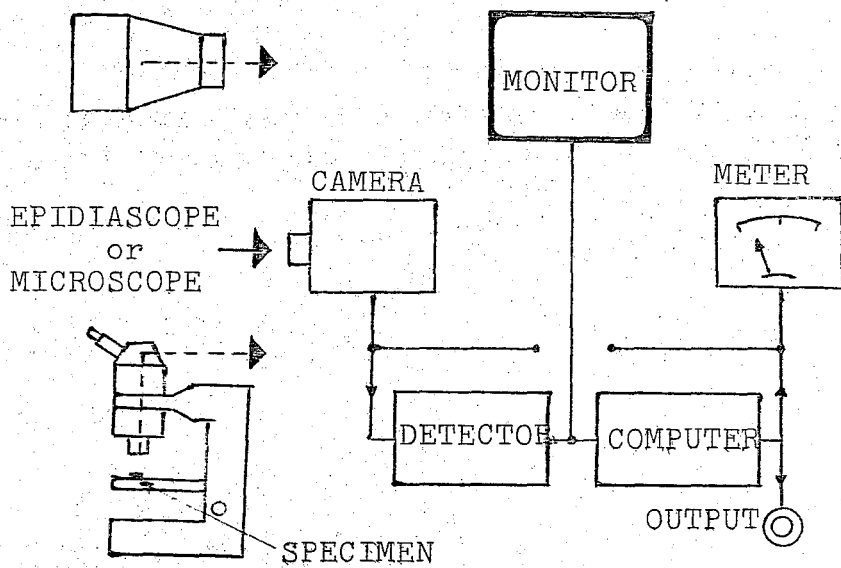


Figure 14. Simplified Block Diagram of Quantimet

Where D.C. = dust concentration, millions of particles per cubic foot of air

C = average dust count per 0.05 mm² field

V = sample volume, ml

A_t = air sample volume, cubic feet

The calculation of coal dust concentration from the Quantimet analysis result is illustrated with the following sample.

Coal Dust Sampling Conditions

Collecting liquid (n-propanol) volume in impinger: 10 ml

Sampling time: 5 min.

Air flow rate: 0.1 cu ft/min (at 12 in. water vacuum)

Quantimet particle count readings per 0.05 mm² field: 15,14,16,20,24

Thus,

$$V = 10$$

$$A_t = 0.1 \cdot 5 = 0.5$$

$$C = (15+14+16+20+24)/5 = 17.8$$

$$D.C. = \frac{C \cdot 20 \cdot V}{1000 \cdot A_t} = \frac{17.8 \cdot 20 \cdot 10}{1000 \cdot 0.5} = 7.12 \text{ mppcf}$$

The coal dust concentration can be converted into gravimetric concentration by the following formula (Ref. 4)

$$5.6 \text{ mppcf} = 1 \text{ mg/m}^3$$

3.4.2 Particle Size Distribution

A Swinney filter holder was modified into a vacuum filter for 1/2 inch diameter membrane filters. Approximately 1 cc of the midget impinger sample was filtered on a 0.22 micron Millipore filter. The filter was allowed to dry, then placed dust side down on a microscope slide. A drop of Duco cement was placed on the filter and the preparation covered with a 18 mm No. 1-1/2 coverglass. The Duco cement was used both to make the paper transparent and as a mounting medium. The coverglass was weighted and the slide was allowed to stand until the cement at the border of the coverglass had hardened.

The measurements were made with a compound microscope fitted with a 97X, 1.25 N.A. oil immersion objective, a 1.25 N.A. Abbe condenser and a 10X ocular. The ocular was fitted with a micrometer and Kähler illumination was used with the iris diaphragm closed slightly to produce sufficient contrast for the small particles to be seen.

The class intervals are an arithmetic progression of the divisions of the micrometer. Each division of the micrometer was calibrated to equal 0.5 micron, therefore the class intervals equaled:

0 - 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 3.5
3.5 - 5.5
5.5 - 8.0
8.0 - 11.0
11.0 - 14.5
14.5 - 18.5
18.5 - 23.0
<23.0

Coal dust samples were analyzed for their particle size distribution with a compound microscope (from American Optical).

The particles in three strips, equally spaced across the mount and the width of the micrometer, were measured. Approximately 250 particles were measured for each sample.

The diameter measurements were made assuming random orientation of the particles. The diameter of each particle was defined as its largest vertical dimension in the microscope field and tabulated according to class intervals.

The coal dust samples from the Bureau of Mines were analyzed first with the results listed in Table 20.

Table 20

ANALYSIS OF COAL DUST PARTICLE SIZE AND DISTRIBUTION

<u>Particle Size Range (microns)</u>	<u>Sample J-39793 (Volatile matter 41.5%)</u>	<u>Sample J-39897 (Volatile matter 16.2%)</u>
0 - 2	26.7%	23.6%
2 - 4	33.0	49.3
4 - 8	23.3	13.8
8 - 16	7.8	4.6
16 - 32	3.4	3.6
32 - 64	2.4	2.0
66 - 128	1.9	1.8
>128	1.5	1.3

Both samples had over 80% of fine particles (0-8 microns). Presumably, they were ground coal samples for analysis.

The coal dust samples listed in Table 18 were also analyzed for their particle size distribution. The results are listed in Table 21.

From Table 21, it is evident that coal dust particles were suppressed by foam proportionally in regard to their size distribution.

Table 21

PARTICLE SIZE DISTRIBUTION DATA OF COAL DUST SAMPLES TAKEN BEFORE AND DURING FOAM APPLICATION AT DIFFERENT DUST CONCENTRATION LEVELS

Particle Size (micron)	Sampling Conditions											
	0.04" Cut		0.04" Cut+Foam		0.06" Cut		0.06" Cut+Foam		0.08" Cut		0.08" Cut+Foam	
	N	%	N	%	N	%	N	%	N	%	N	%
0 - 0.5	40	15.7	56	22.4	60	23.0	52	19.6	47	20.3	33	13.2
0.5 - 1.0	78	30.6	71	28.4	86	32.9	85	32.0	71	30.5	70	27.8
1.0 - 2.0	47	18.4	51	22.0	40	15.3	32	12.1	47	20.3	47	18.7
2.0 - 3.5	39	15.3	27	10.8	27	10.4	35	13.2	25	10.8	33	13.2
3.5 - 5.5	22	8.6	17	6.8	20	7.8	23	8.7	17	7.3	31	12.3
5.5 - 8.0	11	4.3	15	6.0	15	5.7	19	7.3	12	5.2	16	6.4
8.0 - 11.0	8	3.1	4	1.6	2	0.8	11	4.2	8	3.5	3	1.2
11.0 - 14.5	2	0.8	2	0.8	4	1.5	3	1.1	2	0.9	8	3.2
14.5 - 18.5	5	2.0	1	0.4	3	1.1	0	0	1	0.4	5	2.0
18.5 - 23.0	1	0.4	2	0.8	1	0.4	2	0.7	1	0.4	2	0.8
>23.0	2	0.3	0	0	3	1.1	3	1.1	1	0.4	3	1.2
TOTAL	255	100	250	100	261	100	265	100	232	100	251	100
0 - 5.5	226	88.6	222	90.4	233	89.4	227	85.6	207	39.2	214	35.2
Particle Count (mppcf)	38.86		4.8		56.00		1.6		70.44		0.5	

N= number of particles

4. CONCLUSIONS

- (1) This study demonstrated very clearly that respirable coal dust can be generated, sampled, and suppressed by foam application with a coal mining model in our laboratory.
- (2) A foam formulation was successfully developed that can be used to suppress respirable coal dust. It also binds the wetted coal dust and thus reduces the possibility of reaerosolization.
- (3) Foam suppression of coal dust was shown to be feasible in laboratory work. 90-95% reduction in the level of dust was achieved when foams were used..

5. RECOMMENDATIONS

- (1) The encouraging results from this study justify further work to demonstrate the effectiveness in suppression of respirable coal dust in actual coal mine tests. A foam generator should be designed and fabricated. It should be compatible with a selected mining machine and the machine's operation. This work should be conducted in close collaboration with a coal mine and a mining machinery manufacturing company.
- (2) It would be more economical and practical to prepare foam solution as a concentrate and to dilute it. This would reduce the amount of water that would have to be shipped. The concentrated foam solution would be used directly in the foam generator by aspiration or by other means of proportioning it into the water supply.
- (3) Coal mining is a complex technical operation. Such additional effects of using foam factors, as the following, should be investigated.
 - . Effect of foam on mining machine productivity
 - . Need for changes in the make of operation of the mining machine
 - . Effect of foam on maintenance
 - . Overall cost of foam
 - . Beneficial side effects that may occur when foam is used, such as binding of dust and the reduction in so-called float dust
 - . Effect of using foam on such operations as coal cleaning and transportation.

6. BIBLIOGRAPHY

1. Kobrick, Tom, "Water as a Control Method, State of the Art, Sprays and Wetting Agents", Bureau of Mines Information Circular 8458, Proceedings of the Symposium on Respirable Coal Mine Dust, Washington, D.C., November 3-4, 1969 (1970) PP 123-132.
2. Anderson, Floyd G., "A Technique for Counting and Sizing Dust Samples with a Microprojector", American Industrial Hygiene Association Journal, 23, 330-336 (1962).
3. Cole, M., "The Metal Research Quantimet (Q.T.M.)", The Microscope and Crystal Front, Vol. 15, No. 4, May-June 1966, PP 148-160.
4. Jacobson, Murray, and T. F. Tomb, "Relationship Between Gravimetric Respirable Dust Concentration and Midgt Impinger Number Concentration", American Industrial Hygiene Association Journal, 28, 554-556 (1967).

7. APPENDIX

7.1 MATERIALS USED AND EVALUATED

Water

Dayton city water - total dissolved solids = 242 ppm
Deionized water - total dissolved solids = 6 ppm
Distilled deionized water - total dissolved solids = <0.5 ppm

Foaming Agent and Substitutes Evaluated

Hi-EX 15AE + 35 from Walter Kidde Co.
National High Expansion Foam Liquid from National Foam System
Amidex C-2 from Stepan Chemical Co.
Deriphath 151 from General Mills
Neodol 23-3A from Shell Chemical Co.
Neodol 25-3A from Shell Chemical Co.
Steol CA-460 from Stepan Chemical Co.
Triton X-301 from Rohm and Haas Co.

Anionic Surfactants

Acto 450 from Humble Oil & Refining Co.
DDBSA 99-B from Monsanto Co.
DDBSA 99-UB from Monsanto Co.
Dowzit AHB from W. J. Meyers Co.
Igepon AC-78 from General Aniline & Film Corp.
Monawet MO-70 from Mona Industries
Santomerse ME-B Slurry from Monsanto Co.
Sipex JKB from Alcolac Chemical Corp.

Cationic Surfactants

Aliquat 21 from General Mills
Aliquat 33 from General Mills
Atlas G-2090 from Atlas Chemical Industries
Emcol E-12 from Witco Chemical Co.
Katapol PN-430 from General Aniline & Film Corp.
Monazoline O from Mona Industries
Monazoline T from Mona Industries
Romine O from Rozilda

Nonionic Surfactants

Barlox E10S from Baird Chemical Industries
Brij 35 from Atlas Chemical Industries
Emulphor ON-870 from General Aniline & Film Corp.
Hallcomid M8-10 from C. P. Hall Co.
Igepal CO-630 from General Aniline & Film Corp.
Igepal CO-730 from General Aniline & Film Corp.
Kyro EOB from Proctor and Gamble
Lubrol WZ from I.C.I.
Peregal O from General Aniline & Film Corp.
Poly-Tergent J-300 from Olin Mathieson Chemical Corp.
Renex 30 from Atlas Chemical Industries
Sterox AJ from Monsanto Co.
Tergitol 15-S-9 from Union Carbide Corp.
Tergitol TMN from Union Carbide Corp.
Tetronic 702 from Wyandotte Chemicals Corp.
Tetronic 1102 from Wyandotte Chemicals Corp.
Tetronic 1302 from Wyandotte Chemicals Corp.
Triton X-100 from Rohm & Haas Co.

Nonionic Surfactants with Cationic Nature

Amidex C-5 from Stepan Chemical Company
Amidex L-5 from Stepan Chemical Company

Ampholytic Surfactant

Atlas G-3780A from Atlas Chemical Industries

Experimental Surfactants

R35 15-11 from Mona Industries
R35 15-40 from Mona Industries
R35 15-54 from Mona Industries

Polymer and Chemicals

Calcium oxide from Allied Chemical Corp.
Compressed carbon dioxide from Air Reduction Co.
Elvanol 51-05, 52-22, 72-51, 72-60, 73-125 from DuPont Co.
EMA-11, -21, -22, -31, -54, -1103 from Monsanto Co.
Gelvatol 20-30 from Monsanto Co.
Good-Rite K-702 from B. F. Goodrich Chemical Co.
n-Propyl alcohol from Matheson Coleman & Bell
Type 610 gelatin from Swift & Co.

Coal and Coal Dust

Coal

- Seven large bituminous coal lumps from Mathies Mine, Pennsylvania.
- One large bituminous coal lump from West Virginia, mine source unknown.

Coal dust samples from the Bureau of Mines

<u>Lab No.</u>	<u>Source</u>
J-39565	McDowell, W. Virginia and Buchanan, Virginia
J-39793	Knox, Illinois
J-39897	Raleigh, W. Virginia
J-40136	Williamson, Illinois
J-40223	McHenry, North Dakota
J-41321	Williamson, Pennsylvania
J-41373	Schuylkill, Pennsylvania

7.2 EQUIPMENT USED

- Horizontal boring machine from Lucas Machine Tool Co., fitted with a 5 H.P. motor, 3-in. shaft, and a 4-1/2 in. cutter.
- Contact angle measuring device, designed and fabricated by Monsanto Research Corporation with goniometer from Gaertner Scientific Coprp.
- MSA Midget Impinger with 9 all-glass impinger units from Mine Safety Appliances Co.
- Lab vacuum pump (Disto-Pump, Model R-1399) from Welch Scientific Co.
- Manometer from Meriam Instrument Co.
- Quantimet (Q.T.M.) (Metal Research Ltd.)
- Compound Microscope (American Optical)

7.3 PROGRAM OF STUDY

A work program was set up for this study according to the contract objectives. It was outlined in task form as follows:

- I. To Develop a Foam Formulation Suitable for Wetting Down the Coal Dust
 - a. Evaluation of surfactants
 - Compatibility with water
 - Contact angle measurement
 - b. Foam generation
 - General foam formulation
 - Foam generator
 - Modified foam generator
 - Newly developed foam sprayer
 - c. Evaluation of polymers
 - Foaming performance
 - Compatibility with surfactants
 - d. Evaluation of foaming agent Hi-Ex
 - Evaluation of substitutes
 - Evaluation of surfactants as foaming agent
 - e. Evaluation of foam solutions
 - Wettability on coal
 - Expansion factor
 - Effects of water hardness and pH
 - f. Promising foam formulation
- II. Develop a Laboratory Coal Mining Model
 - Selection of simulation method
 - General layout
 - Coal dust generation
 - Coal dust sampling

III. Run a Coal Dust Suppression Experiment

- At low coal dust concentration
- At high coal dust concentration

IV. Analysis of Coal Dust Sample

- Particle count
- Particle size distribution

